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DERIVATION OF PRESBYCUSIS AND NOISE INDUCED PERMANENT THRESHOLD SHIFT (NIPTS) TO BE USED FOR THE BASIS OF A STANDARD ON THE EFFECTS OF NOISE ON HEARING

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FOR THE COMMANDER

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This report provides various sets of tables that attempt to summarize much of the existing knowledge of the expected effects of noise on the hearing threshold levels of a population. Relations between noise exposure and Noise Induced Permanent Threshold Shift (NIPTS) for different audiometric frequencies are provided. Six different data sets of presbycusis (the effects of aging on hearing thresholds) are provided. Details for combining the effect of NIPTS to different presbycusis bases are provided. Three

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methods are suggested for presentation of hearing loss data. These are: (1) direct use of NIPTS, (2) calculation of hearing risk (the change in percent of the population whose hearing exceeds a certain value, and (3) use of a value (called units of potential compensation) that is related to the total compensation that might be paid due to hearing loss. The last method is new and was developed especially because of criticisms of the first two methods. The combined average of the frequencies of 500 Hz, 1000 Hz, 2000 Hz and 3000 Hz are analyzed in great detail and 10 tables are provided for describing the effects of noise on this frequency combination. A computer program for calculating hearing risk and units of potential compensation is provided.

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PREFACE

The research described in this report was supported by the Environmental Protection Agency and the Biological Acoustics Branch of the Aerospace Medical Research Laboratory.

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1. INTRODUCTION

In 1977, Dr. Henning E.G. von Gierke, the present chairman of the International Organization for Standardization ISO/TC 43/SC1 "Noise" Working Group on Revision of ISO 1999 "Acoustics-Assessment of Occupational Noise Exposure for Hearing Conservation Purposes," asked the author to prepare a set of tables that best summarize the existing knowledge of the effects of noise exposure on the hearing threshold levels of a population. Subsequently, Dr. Tonndorf, as chairman of ANSI Working Group S3-58, requested similar information. In response to these requests, tables were prepared by the author for consideration by the working groups. The working groups can thus select the tables, if any, that are considered most appropriate to a standard. This is a formal report to the working groups.

In keeping with the above intent, three observations about this report are pertinent. First, the report is not a complete treatise on the effects of noise on hearing. Only those technical areas that were believed to be of interest to the working groups and were in the area of the author's expertise are covered. Second, the report usually provides several approaches without explicitly selecting a preferred approach. It is, of course, up to the working groups to select the approach which is the most appropriate. Thus an ISO or ANSI standard, when agreed upon, will resolve this problem. Finally, the report may not be entirely complete and may require an addendum. For instance, each frequency is not analyzed in the detail that the average of 500, 1000, 2000, and 3000 Hz is analyzed. However, it is unreasonable to analyze each of the 63 possible combinations of the 6 frequencies from 500 to 6000 Hz. On the other hand, the basic procedure for analyzing the average of 0.5, 1, 2, and 3 kHz should apply to the averaging of any other combination of audiometric frequencies.

The organization of this report consists of 17 key decisions. Each key decision is discussed in detail by providing: Approach, Sample Calculation, and Discussion. The approach includes a description of the procedure used and any necessary assumptions required. The sample calculations, if appropriate, are provided to illustrate unequivocally the procedure used. The discussion addresses the reasonableness of both the procedure and any assumptions used.

2. DATA FOR DEPICTING HEARING CHANGES CAUSED BY NOISE

APPROACH

Two basic data bases were selected. One data base is the National Physical Laboratory Report Ac 61 (second edition), June 1977, by D. W. Robinsin and M. S. Shipton.[1] This report provides the same data that previously have been provided in earlier reports by Robinson.[2] The other data base is a 1977 report by Passchier-Vermeer.[3] The data presented in this report are similar to her earlier reports.[4] The study by Baughn[5] was not directly used, but some of the trends in Baughn's data were considered when the rationale for certain assumptions were evaluated. The Inter-Industry Study[15] was also used to ascertain certain correction factors appropriate in the statistical treatment of the data.

SAMPLE CALCULATION

Not appropriate.

DISCUSSION

The studies of Passchier-Vermeer and Robinson were chosen mainly because of their completeness in depicting the effects of noise for various exposure times, levels, frequencies, and population percentiles. While they are not without some technical criticisms, they are on the whole reasonable attempts to describe the effects of noise. Other data bases, including Baughn, are not that complete.

3. SELECTION AS THE BASIC MEASURE OF THE EFFECTS OF NOISE ON THE NOISE INDUCED PERMANENT THRESHOLD SHIFT (NIPTS) FOR VARIOUS POPULATION PERCENTILES

APPROACH

The basic parameter selected for describing the effects of noise on hearing is the difference between the statistical measures of non-noise-exposed population and a noise-exposed population. The statistical measures used were the 10th percentile (.1), the 50th percentile or median (.5) and the 90th prcentile (.9). The 10th percentile is defined as the hearing threshold level (HTL) at which only 10 percent of the population will have higher HTLs (worse hearing). Likewise, 90th percentile is defined as the HTL at which 90 percent of the population have higher HTLs and the median is defined as the HTL at which 50 percent of the population has higher HTLs. The difference in these measures between similar non-noise- and noise-exposed population will be called Noise Induced Permanent Threshold Shift or NIPTS.

SAMPLE CALCULATIONS

Consider the following two groups of people: Group A is a 30 year old group that have not been exposed to occupational noise or military training. At 6000 Hz, 10 percent of group A hear better than 7 dB, 50 percent hear better than 18 dB, and 90 percent hear better than 29 dB, all referenced to the 1964 ISO standard. Group B is also a 30 year old group that have not been exposed to military training, but have been working in an industrial plant for the last 10 years in which the average sound level was approximately 88 dB during the normal 8-hour workshift. At 6000 Hz, 10 percent of group B hear better than 9 dB, 50 percent hear better than 24 dB, and 90 percent hear better than 42 dB, all reference 1964 ISO. Since these two groups are similar except for the occupational noise exposure, NIPTS can be calculated for an exposure to an Average Sound Level of 88 dB for 10 years starting at age 20 years.

The NIPTS is calculated as follows:

90th percentile: 9 dB — 7 dB = 2 dB
median: 24 dB — 18 dB = 6 dB
10th percentile: 42 dB — 29 dB = 13 dB

DISCUSSION

From the above calculations, it can be seen that NIPTS, as defined here, is a measure of the changes in the statistical distribution of hearing levels. As such, individual changes are not known. This point needs to be mentioned whenever such data are used.

While in the above example the two groups were stated to be similar in all aspects except for noise exposure, in the practical world this is never completely true. The two groups might live in different areas of the country, might have different male-female ratios, different socioeconomic backgrounds, different nonoccupational activities, etc. While a perfect match is probably impossible, the better the two groups are matched, the better the NIPTS data.

4. USE OF DATA FROM PASSCHIER-VERMEER

APPROACH

The data used in this report came from a 1977 report of Passchier-Vermeer (see ref 3). The NIPTS for the median are found in Table A1 (page 12) of her report. The data are also provided in table 1* of this report. The NIPTS values for the 10th and 90th percentiles are not directly reported in her paper since she has averaged these values over time. In order to avoid this averaging (see the reasons for doing this in the following discussion) the values of table B5 of her report (p. 21) are used to modify the Median NIPTS values given in table 1. Specifically:

NIPTS(.1) = NIPTS(.5) + Δ10%

where NIPTS(.1) is the NIPTS of the 10th percentile, NIPTS(.5) is the NIPTS of the median, and 10% is a value given by Table B5 in ref 3

and NIPTS(.9) = NIPTS(.5) — Δ90%

where NIPTS(.9) is the NIPTS of the 90th percentile and Δ90% is a value given in table B5 of ref 3.

These values of NIPTS(.1) and NIPTS(.9) are summarized in table 1 (this report) for various frequencies and average sound levels.

*All figures and tables appear at the end of the main text.

SAMPLE CALCULATIONS

(1) Consider the NIPTS for 20 years of exposure to 95 dB at 2000 Hz. Table A1 of ref 3 gives NIPTS(.5) as 9.0 dB. Table B5 gives Δ10% as 8 dB and Δ90% as 5 dB.

Then NIPTS(.9) = 9 — 5 = 4 dB

NIPTS(.5) = 9 db

NIPTS(.1) = 9 + 8 = 17 dB

Note these values are given in table 1 for a 20-year exposure to an average sound level of 95 dB.

(2) To provide some insight how Δ10% and Δ90% were derived, data from the example in section 3 of this report were used to derive Δ10% + Δ90% per Passchier-Vermeer.

Δ10% = (42 — 29) — (24 — 18) = 13 — 6 = 7

Δ90% = (24 — 9) — (18 — 7) = 15 — 11 = 4

Then NIPTS(.9) = NIPTS(.5) — Δ90% = 6 — 4 = 2

and NIPTS(.1) = NIPTS(.5) + Δ10% = 6 + 7 = 13

These of course, are the values of NIPTS calculated in the example of section 3. The reader should read Passchier-Vermeer's report further if more detail is desired.

(3) Sample of averaging Δ10% and Δ90% over time by Passchier-Vermeer instead of not averaging over time. The main deviation in this report from Passchier-Vermeer's report is that her corrections Δ10% and Δ90% are not averaged over time. These examples should illustrate the effect of such averaging.

Consider the effect on 2000 Hz of an exposure of 95 dB for 10, 20, 30, and 40 years. The median NIPTS from Table A1 is 4.8, 9.0, 13.5, and 18.0 for 10, 20, 30, and 40 years respectively. Similarly, Δ10% is 9.8, 8.0, 6.0, and 3.6. Using the method proposed in this document, NIPTS(.1) would be 14.6(4.8 + 9.8), 17, 19.5 and 21.6 for the various exposure durations. These values are shown in table 1. Passchier-Vermeer proposes first averaging Δ10%. Such an average would be (9.8 + 8 + 6 +3.6)/4 = 6.8. These averages values are given in table B6 of Passchier-Bermeer's report. The average value is then added to the median NIPTS to calculate NIPTS for the 90th percentile. Specifically, NIPTS(.9) for 10, 20, 30, and 40 years of exposure would be 11.6 (4.8 + 6.8), 15.8 (9.0 + 6.8), 20.3, and 24.8

DISCUSSION

The basic data used by Passchier-Vermeer are a compilation from many studies (see ref 4) and as such provide one reasonable data base. The one deviation from her 1977 proposal is with respect to averaging over time the differences between the median and the other percentiles. Since there is no theoretical or practical reason to expect such differences for any frequency to remain constant, this averaging was eliminated in this report. Elimination of such averaging is believed to provide a more realistic picture of what actually occurs when a population is exposed to noise. For instance the values of NIPTS(.1) for the frequencies 2000 Hz and above increase much more rapidly than NIPTS(.5) for 10 and 20 year exposures. On the other hand, for 30-year and 40-year exposures there may be little difference between NIPTS(.1) and NIPTS(.5). This phenomenon is also seen in Baughn's data[5] and to some extent in the NIOSH study.[6]. Averaging the differences between NIPTS(.1) and NIPTS(.5) eliminates this phenomenon. Since there is no reason to believe that this phenomenon is not true, this averaging was rejected. Note: If it is assumed that noise exposure can cause only so much hearing loss, for instance 70 dB, this phenomenon would be predictable.

5. USE OF DATA FROM ROBINSON

APPROACH

In reference 1, tables are provided that can be used to obtain the various values of H′ directly in terms of noise emission level. Noise emmission level (E_A) is defined as the 8-hour average sound level plus ten times the $\log_{10}$ of T, where T is in years. NIPTS is based on the difference of H′ as based on a calculating H′ for an 8-hour average sound level above 75 decibels and for an H′ based on an average sound level of 75 dB.

NIPTS(.5) is obtained directly from table 6 of ref 1 by using the 50 percent column. NIPTS(.1) is obtained by subtracting 7.7 dB from the value given in the 10 percent column and NIPTS(.9) is obtained by adding 7.7 dB from the values given in the 90 percent columns. A listing of the NIPTS for various frequency and average sound levels is given in table 2.

SAMPLE CALCULATIONS

Consider the effect of 2000 Hz for a 20-year exposure to an occupational 8-hour daily average sound level of 95 decibels. The emmission level, E_A is $95 + 10 \log 20 = 95 + 13 = 108$. For an emission level of 108, table 6c of reference 1 gives a HTL of -4.0 decibels for the 90% column, 9.2 decibels for the 50% column, and 27.5 for the 10% column.

Likewise, the emission for the 75 dB level is 75 dB + 13 dB = 88 dB. Using the same table 6c of ref 1, an HTL of —7.4 dB for the 90% column, 0.8 dB for the 50% column and 9.8 dB for the 10% column, NIPTS can then be calculated as

NIPTS(.9 = —4.0 — (—7.4) = 3.4 dB
NIPTS(.5) = 9.2 — 0.8 = 8.4 dB
NIPTS(.1) = 27.5 — 9.8 = 17.7 dB
These values are those shown in table 2.

DISCUSSION

The treatment of Robinson's data is rather straightforward. One possible assumption would be in considering that the distribution of the non-noise population remains completely Gaussian with a constant standard deviation of 6 dB even as the median hearing level increases with age. This assumption produces a finite, albeit small amount of NIPTS at an average exposure of 75 dB. If, on the other hand, the non-noise exposure was considered as 75 dB, which is not an unreasonable level in view of some recent dosimeter studies,[7] the NIPTS at 75 decibels would disappear. There is also a valid question as to the accuracy of Robinson's tables for these average sound levels below 80 decibels. Robinson's data base did not include data for these low exposure levels, so the NIPTS predicted is from higher exposure levels. Therefore, 75 dB is selected as the threshold of NIPTS for the Robinson Model and this threshold is used in this report. The decision to consider as negligible the effects of an 8-hour daily exposure to 75 dB has been supported by three recent studies. Melnick;[8] Stephenson, Nixon and Johnson;[9] and Mills, Gilbert, and Adkins[10] have all shown that 24-hour exposures to broad band noise with equal sound pressure level per octave band (pink noise) does not result in a statistically significant Temporary Threshold Shift at any audiometric frequency measured 2 minutes after 24 hours of exposure. If no temporary changes in auditory acuity occur, it is only reasonable to believe that no permanent changes will occur. Narrow bands of noise or pure tones of 75 dB can cause Temporary Threshold Shifts and some audiometric frequencies, thus 75 dB may not be the "no effect level" for all types of noise exposure. A caveat expressing such a concern is appropriate. A sample caveat is provided for table 3. Nevertheless, since most environmental noise and industrial noise tends to be rather broad band, the 75 dB level is a reasonable and practical threshold below which noise is not expected to be damaging to hearing.

Note that Passchier-Vermeer has also defined all NIPTS at 75 dB to be zero.

6. COMBINING ROBINSON'S AND PASSCHIER-VERMEER'S DATA FOR NIPTS

APPROACH

A simple arithmetic average of the NIPTS values of Passchier-Vermeer (table 1) and of Robinson (table 2) is used to produce table 3. All values are rounded upward to the nearest tenth of 1 dB.

SAMPLE CALCULATIONS

Consider NIPTS(.9) at 2000 Hz for an 8 hour average sound level of 95 dB for 20 years. NIPTS(.9) from table 1 = 17 dB. NIPTS(.9) from table 2 = 17.7 dB. The average NIPTS(.9) of the two data bases equals 17.4 dB as shown in table 3.

DISCUSSION

In general, tables 1 and 2 show a fair agreement between the two sets of data. The biggest difference is the reversal of the value of NIPTS(.1) versus NIPTS(.9) in Passchier-Vermeer's data after 40 years of exposure. Specifically, NIPTS(.9) is greater than NIPTS(.1). Robinson's data did not show such a reversal. As mentioned earlier, Baughn's did show such a reversal. The other difference is in the levels below 80 dB. In any case, the averaging of the two data bases is viewed as a practical means for arriving closer to the true representation of NIPTS.[11] For exposures of 40 years for the HTLs of the combined frequencies of .5, 1 and 2 kHz, the NIPTS data from Baughn is usually between Passchier-Vermeer's and Robinson's values. An average of Robinson's data and Passchier-Vermeer's often closely matches Baughn's NIPTS data at NIPTS(.1) and NIPTS(.5). For a summary of such comparisons, see table 4. While there are several differences between Passchier-Vermeer's and Robinson's data of more than 6 decibels, the greatest difference between the combined data and Baughn's is at the most 2 dB. Since Baughn's 40-year exposure data is believed to provide a reliable measure (the absolute hearing threshold levels were high enough so masking and TTS should not have been a problem), this provided convincing evidence that combining the data of Passchier-Vermeer and Robinson apparently does provide a more accurate prediction of NIPTS than using either alone.

7. COMBINING NIPTS DATA OF DIFFERENT FREQUENCIES INTO NIPTS FOR A COMBINATION OF FREQUENCIES

APPROACH

In order to calculate NIPTS for a combination of frequencies, an arithmetic average of the NIPTS at each frequency is used. All rounding was to the next higher tenth of 1 dB. A summary of NIPTS average over several frequencies is given in table 5.

In several cases the NIPTS at 40 years of exposure was one- or two-tenths of 1 dB lower than the NIPTS at 30 years. Where this occurred, table 5 was adjusted so that NIPTS at 40 years was always equal to or greater than the NIPTS for the shorter exposure durations.

SAMPLE CALCULATIONS

(1) Find the NIPTS(.1) for the combined frequencies of .5 kHz, 1 kHz, 2 kHz and 3 kHz for 85 dB after 20 years. From table 3:

NIPTS(.1) for 500 Hz = 1.2
1000 Hz = 1.9
2000 Hz = 4.8
3000 Hz = 7.8
15.7

NIPTS(.1) for .5, 1, 2, 3 kHz is 15.7/4 = 3.9

(2) The average NIPTS(.1) at .5, 1, 2, 3 kHz for an average sound level of 90 dB was 9.1 dB for 30 years exposure and 8.8 for 40 years exposure. These values were both set to 9.0 dB in table 5.

DISUCSSION

Averaging the NIPTS data of several frequencies is a necessity since data where the frequencies are first averaged in individuals, then NIPTS calculated, are generally not available. A slightly different value would be expected if individual averaging were used. However, this same problem is also apparent when the effect of aging (presbycusis) is considered. In a later section, a correction for averaging presbycusis data over several frequencies is recommended. This correction factor also approximately corrects for any error expected in the NIPTS data once the NIPTS data is added to the presbycusis data.

The changing of all NIPTS values by 0.1 or 0.2 dB so that NIPTS always grows with exposure is necessary to avoid a possible misinterpretation of the data in some of the later analysis. Providing NIPTS data to the nearest tenth decibel in no way implies that the accuracy of the NIPTS data is known to such a degree. The purpose of using the nearest tenth of a decibel is only to avoid unnecessary error that might occur in rounding the data too soon in the analysis.

8. DERIVING THE PRESBYCUSIS DATA FROM PASSCHIER-VERMEER

APPROACH

In her report (ref 3) Passchier-Vermeer provided tables that allow the direct calculation of an aural pathology-free, non-noise-exposed population (in dB re the 1964 ISO standard). The median hearing threshold level [HTL(.5)]is given in table I (page 3 of ref 3). The hearing threshold level exceeded by 10% of the population [HTL(.1)]is given by adding the values of table II (ref 3) to HTL(.5). The hearing threshold level exceeded by 90% of the people is given by subtracting the values of table III (ref 3) from HTL(.5). A summary of these values is given in table 6.

SAMPLE CALCULATIONS

Consider that the HTL at 2000 HZ of a 40 year old population is desired. Tables, I, II and III of ref 3 are to be used.

The median HTL is taken from table I (ref 3) and is 4 dB. The HTL (.1) is equal to 4.0 plus the value of table II (ref 3) or on 4.0 + 9.2 = 13.2 dB. HTL(.9) is equal to 4.0 minus the value of table III (ref 3) or 4 — 9 = 5.0 dB. The values are those given in table 6 of this report.

DISCUSSION

None

9. DERIVING THE PRESBYCUSIS DATA FROM ROBINSON

APPROACH

The population was assumed to be exposed to a nonoccupational noise of 75 dB. Thus an emmission level for 75 decibels was used to obtain values from table 6 of reference 1. These values were added to table 4 of reference 1. Specifically, for some frequency:

HTL(.1) = the value of the 10 percent column of table 6 (ref 1) for 75 + 10 log T (where T = age (N) in years — 20) plus the value of table 2 (ref 1) for the appropriate age (N) in years.

Similarly

HTL(.5) = 50% column of table 6 (ref 1) plus the appropriate value of table 3 (ref 1)

and

HTL(.9) = appropriate value of 90% column of table 6 (ref 1) plus appropriate value of table 2 (ref 1)

A summary of these values is given in table 6 of this report.

SAMPLE CALCULATIONS

Calculate HTL(.9), HTL(.5), HTL(.1) for 2000 Hz at age 30.

Emmission level is 75 + 10 log (30—20) = 85. For an age of 30, the age correction from table 2 (ref 1) is .6 dB for 2000 Hz. For an emmission level of 85, 10% column gives 9.1, 50% column gives .5, and 90% column gives —7.5. Thus,

HTL(.9) = —7.5 + .6 = —6.9
HTL(.5) = .5 + .6 = 1.1
HTL(.1) = 9.1 + .6 = 9.7

DISCUSSION

The major deviation from Robinson's proposed method of calculating presbycusis is the assumption that even the nonindustrial noise-exposed population is receiving an average noise exposure of 75 dB. This assumption has been supported by a recent report by Schori.[7] A study of 50 typical Americans indicated that the median exposure was an average sound level of 74 dB. This assumtpion causes, for the most part, only minor adjutments (1 or 2 dB) in the presbycusis values for all except the higher frequencies at 50 or 60 years. In the latter cases, this assumption elevates the HTL(.1) values by as much as 6 or 7 dB. However, with this assumption, there is excellent agreement between the presbycusis data of Passchier-Vermeer and Robinson. The greatest deviation came again at the older ages at the higher audiometric frequencies. For instance, at 3000 Hz at age 60 years, HTL(.1) from Passchier-Vermeer data is 39.1, while HTL(.1) from Robinson data is 26.4. If the assumption of a 75 dB exposure were not used, Robinson's HTL(.1) would be an even lower 20.5 dB. In summary, the presbycusis data of Robinson without such an assumption provides age effects that are unrealistic. Robinson cautions against using table 2 (ref 1) as a presbycusis data base and his point is well taken. If Robinson's data are realistic at all, then such an adjustment caused by the 75 dB exposure assumption should make the data comparable to the data of other investigators.

10. DESCRIBING PRESBYCUSIS DATA FROM THE PUBLIC HEALTH SURVEY OF 1960-62

APPROACH

The hearing threshold levels were taken from reference 12. The data, which were based on the 1951 ASA standard, were corrected to the 1964 ISO audiometric standard. Tables 8, 9, 10 of reference 12 were used. These tables provide percentage distributions of hearing levels for the *better ear* for men and women. The data are provided in 10 dB intervals. Therefore, the data were plotted on probability paper and the values of HTL(.1), HTL(.5) and HTL(.9) were estimated by drawing curves fitted by eye. Figure 1 provides an example of the technique used. Only HTL(.9) required extrapolation, and then only at some frequencies. When such extrapolations were required, the data on 6-11 year old children [13] and 12-17 year old children[14] were used as guidance. The female data are reported in table 7 and the male data are reported in table 8 of this report.

SAMPLE CALCULATIONS

Calculate HTL(.9), HTL(.5) and HTL(.1) at 1000 Hz for males at age 60 from the Public Health Service (PHS) data. From table 8,[11] for men ages 55-64 years, the following data are given:

44.3 percent hear —5 dB (re 1951 ASA) or less

36.6 percent hear —4 to +5 dB (re 1951 ASA). Likewise, 12.7 percent hear +6 to +15, 2.2 percent hear +16 to +25, etc. The adjustment from 1951 ASA to 1964 ISO requires that 10 dB be added to each of the stated interval levels of table 8. Thus 44.3 percent of the population have a HTL of +5 dB or less, 36.6 percent have a HTL of +6 to +15 dB, etc. Cumulative percentages are calculated as follows:

Percent that hear better than:	Percent
+5 dB	0 + 44.3 = 44.3
15 dB	36.6 + 44.3 = 80.9
25 dB	12.7 + 80.9 = 93.6

These values can then be plotted on probability paper as is done in figure 1. In order to estimate HTL(.9), a line is drawn parallel to a line connecting data from 11 year old and 17 year old persons from the Public Health Service data. The value of HTL(.9) can then be estimated by the intersection of the vertical line, indicating 10 percent of the population have better hearing. In this case, HTL (.9) was —2 dB. Similarly HTL(.5) was found to be 6 dB and HTL(.1) was 21 dB. Notic all values were rounded to the next closest integer representing better hearing.

DISCUSSION

The above approach should provide reasonable estimates of the hearing levels from the Public Health Service data. In general, the hearing levels at any frequency did not deviate much from a normal distribution until the worse hearing 5-10% of the population. The extrapolations required to estimate HTL(.9) are only required when the hearing levels of HTL(.9) are better than +5 to 9 dB, depending on frequency. When HTL(.9) is above 9 dB, it will always have been predicted by interpolation.

11. COMBINING PRESBYCUSIS DATA OF PASSCHIER-VERMEER AND ROBINSON

APPROACH

A simple arithmetic average was used. All rounding was to the next highest tenth. A summary of combined data is provided in table 9.

SAMPLE CALCULATION

None

DISCUSSION

None

12. COMBINING HEARING THRESHOLD LEVELS OF SEVERAL FREQUENCIES

APPROACH

As with the NIPTS data, the HTL value for each frequency is summed and the total sum is divided by the number of frequencies considered. Thus HTL(.9) at 1/4(.5, 1, 2 & 3) is equal to 1/4 times (HTL(.9) at .5 kHz + HTL(.9) at 1 kHz + HTL(.9) at 2 kHz + HTL(.9) at 3 kHz).

The values of HTL for the combined frequencies of .5, 1, 2, and 3 kHz are given in table 10 for each of the presbycusis data bases. In addition, corrected HTL values for these four frequencies are given in table 10. The corrected data is obtained by subtracting 2 decibels from HTL(.1) and adding 2 decibels to HTL(.9). This correction, which only applies when combining the four frequencies of .5, 1, 2 and 3 kHz, is discussed in paragraph 13.

SAMPLE CALCULATION

Calculate HTL(.1) for 40 year olds, using women from the PHS as the presbycusis data base, for .5, 1, 2 and 3 kHz.

$$\begin{aligned} \text{HTL}(.1) \text{ at } 500\ \text{Hz} &= 19 \\ 1000\ \text{Hz} &= 13 \\ 2000\ \text{Hz} &= 13 \\ 3000\ \text{Hz} &= \underline{18} \\ & 63 \end{aligned}$$

HTL(.1) at (.5, 1, 2, 3) = 63/4 = 15.8 dB.

corrected HTL(.1) = 15.8 − 2 = 13.8 dB

DISCUSSION

See discussion in sections 7 and 13.

13. CORRECTION TO THE STATISTICAL DISTRIBUTION TO BE USED WHEN ESTIMATING THE HEARING THRESHOLD LEVELS OF SEVERAL COMBINED FREQUENCIES.

APPROACH

Some of the data from audiograms of participants of the inter-industry noise[15] study were used to develop the correction discussed herein. The data were divided into three main groups: (1) a good hearing group of 94 females (188 ears), whose median hearing level of (.5, 1, 2, 3) kHz was 5 decibels, (2) a medium hearing group of 58 males (116 ears) whose median hearing threshold level at (.5, 1, 2, 3) kHz was 13 decibels, and a poor hearing group of 69 males (138 ears) whose median hearing level was 23 dB. For each of the groups, distributions of the hearing levels at each separate frequency were prepared. The hearing levels for the combined frequencies of each individual were also calculated and the distribution of these individual hearing levels was constructed. The HTL for various percentiles was then estimated from combining the percentiles of the distributions for each frequency. This value was compared using the HTL of individual data. A linear regression of the difference for various percentiles against Z, where $Z = \dfrac{\text{HTL}(.5) - \text{HTL}(x)}{\text{Standard Deviation}}$ was made and the necessary correction for HTL(.1) and HTL(.9) were estimated from the average of these regression curves.

SAMPLE CALCULATIONS

To illustrate the need for a correction, a simple problem will suffice. Consider audiometric data of five individuals:

	.5 kHz	*1 kHz*	*2 kHz*	*3 kHz*	*Ave [0.5,1,2,3]*
Subj No. 1	5	0	10	15	7.5
Subj No. 2	10	5	5	5	7.5
Subj No. 3	0	5	10	5	4.0
Subj No. 4	10	10	5	10	9.0
Subj No. 5	0	5	15	20	10.0

The worst hearing subject's HTL of the combined frequency 1/4(.5, 1, 2, 3) kHz is 10 decibels. On the other hand, if the worst hearing level at each frequency were used to estimate HTL of the worst hearing individual, the levels of 10 dB for 500 Hz, 10 dB for 1000 Hz, 15 dB for 2000 Hz and 20 dB for 3000 Hz would be averaged as $\sim$14 dB. In this case an error of 4 decibels was made in using the distribution data from each frequency for estimating the actual distribution for individuals.

2. To illustrate the details of the regression analysis, the errors for group 3 are summarized in table 11. The 138 audiograms were rank ordered for each frequency as well as for the individual combination of (.5, 1, 2 and 3) kHz. Every 5th audiogram was used as a data point and as shown in table 11, the differences between adding the individual columns for .5, 1, 2, 3 versus the actual hearing levels of individuals were calculated as error. The quantity $\frac{x}{138}$ provides the percentile of the population considered and Z was calculated for that percentile assuming a standard deviation of 1. A standard linear regression of error against Z was calculated. The results of the three groups were:

Group No. 1 error = .04 + 1.33Z
No. 2 error = —.09 + 2.18Z
No. 3 error = —.34 + 2.22Z

considering Z = 1.28 for the 10th percentile and Z = —1.28 for the 90th percentile, the error predicted for HTL(.1) is 1.74 for Group 1, 2.5 for Group 2 and 2.7 for Group 3. This is an average of 2.3 or approximately 2.

DISCUSSION

If for an individual, the HTL at one frequency were statistically independent of the HTL at the other frequencies, then the amount of error could be estimated by known statistical procedures. For instance if the standard deviation of each frequency were 6 dB, combining the four frequencies would produce a distribution with a standard deviation of 3 dB. Thus the error expected for HTL (.1) would be 1.28 x 6 — 1.28 x 3 = 3.84 dB.

However, in an individual, the frequencies are not independent of each other. For instance, a person with a noise induced loss at 3000 Hz would also be more likely to have a noise induced loss at 2000 Hz. Thus, the procedure described above provides an empirical estimate of the correction needed. While it was initially thought that a greater correction might be needed for the poorer hearing populations, the lack of difference between groups 2 and 3 indicate that this is not necessarily true. The explanation, of course, is that in the poorer hearing groups there is more correlation between the HTL of each frequency in an individual. In the extreme, if there were perfect correlation between frequencies, no correction would be needed at all. For example, if subject 5 of example 1 had the highest hearing level of the five subjects at each frequency, then there would have been no error in calculating the worst hearing individual.

The final correction proposed is a 2 decibel adjustment to HTL(.1) and HTL(.9). This in effect provides correction based on:

$$\text{error} = 0 + \frac{2}{1.28} Z$$

While this is a few tenths of a decibel lower than what might be used for groups 2 and 3, this 2 dB correction should give a conservative estimate of the distribution of HTL's when the frequencies of individuals are combined.

14. GENERALIZATION OF THE ADDITION OF NIPTS TO ANY REASONABLE PRESBYCUSIS DATA BASE

APPROACH

The addition of NIPTS to presbycusis will result in a value that, for simplicity, will be called the noise impacted hearing threshold level. To estimate the final noise impacted Hearing Threshold Level (NHTL) the NIPTS associated with a certain noise exposure is simply added to the HTL expected due to presbycusis.

Thus, for some percentile x,

NHTL(x) = NIPTS(x) + HTL(x)

where NIPTS(x) is a value from tables 3 or 5 and HTL(x) is a value from tables 7, 8, or 9, or some other appropriate table.

For $x < .5$, a normal distribution is assumed between .01 and .5 with a standard deviation of $\frac{\text{NHTL}(.1) - \text{NHTL}(.5)}{1.28}$

For $x > .5$, a normal distribution is assumed between .5 and .99 with a standard deviation of $\frac{\text{NHTL}(.5) - \text{NHTL}(.9)}{1.28}$

Whenever NHTL, as calculated by this approach, is between 50 and 70 decibels a caveat to the effect that the actual NHTL(x) may be a few decibels lower should be included. Whenever NHTL calculated by this approach is above 70 decibels, a caveat to the effect that the actual NHTL(x) may not greatly exceed 70 decibels should be mentioned.

SAMPLE CALCULATIONS

Calculate the hearing levels for the 5th percentile, 10th percentile, median, and 90th percentile at 2000 Hz expected in a U.S. female population at age 40 after 20 years of daily occupational exposure to an average sound level of 90 decibels for 8 hours. From table 3 NIPTS(.1) = 9.3 dB, NIPTS(.5) = 3.9 dB, and NIPTS(.9) = 1.6 dB. From table 7 HTL(.1) = 13 dB, HTL(.5) = 2 dB, and HTL(.9) = —4 dB.

Therefore

$$\text{NHTL}(.1) = 9.3 + 13 = 22.3\text{ dB}$$
$$\text{NHTL}(.5) = 3.9 + 2 = 5.9\text{ dB}$$
$$\text{NHTL}(.9) = 1.6 - 4 = -2.4\text{ dB}$$

To calculate NHTL(.05), a graphic approach on probability paper could be used as is done in Figure 2. Alternatively, for a normal curve, the value Z for .05 is 1.645. Thus NHTL(.05) can be calculated by:

$$\begin{aligned}\text{NHTL}(.05) &= 1.645 \times \frac{\text{NHTL}(.1) - \text{NHTL}(.5)}{1.28} + \text{NHTL}(.5)\\ &= \frac{1.645}{1.28}(16.4) + 5.9\\ &= 27.0\text{ dB}\end{aligned}$$

Calculate the hearing levels at 4000 Hz not exceeded by more than 10 percent of the individuals of a random sample of United States male workers at age 60 who have been exposed to 95 decibels of occupational noise for 40 years.

Using table 8 at age 60 HTL(.1) for 4000 Hz is 68 decibels. NIPTS(.1) for a 30 year exposure to an average sound level of 95 decibels is 27.6. NHTL would be 68 + 28 = 96 decibels, a value that requires the proposed caveat since NHTL is clearly above 70 decibels. In this case, Baughn's report might be consulted to obtain a better estimate. For instance, at 4 kHz Baughn's NHTL(.1) for a 78 dB exposure is 71 dB for a 54-59 age group.[5] At 92 dB, Baughn's data indicate an NHTL(.1) of only 77.4 dB, or only a 6 decibel change for a 14 dB increase in level. Thus a 95 decibel exposure to a group of U.S. males might better be expected to result in only a NHTL(.1) of 74-75 decibels (68 + either 6 or 7 dB). This is quite different from 96 dB predicted earlier.

DISCUSSION

The key to the procedure proposed in this document is, for some known noise exposure, the simple addition of the NIPTS at a certain percentile to the HTL of a non-noise exposed population. Specifically, the NIPTS data of tables 3 or 5 can be combined to the presbycusis data of table 7, 8 or 9. The question arises as to the accuracy of this procedure. To answer this question, the discussion will be divided into two considerations: (1) what actual data indicates and (2) some theoretical considerations.

The strongest support of adding the NIPTS data to any presbycusis base with hearing levels at or between the good hearing of table 9 and the relatively poor hearing of table 8 is based on this fact: Although the presbycusis data assumed by Robinson, Passchier-Vermeer and Baughn differed by a considerable amount, the NIPTS data itself was quite comparable. For instance consider again table 4.

Also consider at age 60 for 1/3(.5, 1, 2) that HTL(.1) from Robinson's presbycusis base is 17 decibels, from Passchier-Vermeer's presbycusis base is 21 dB, and from Baughn's presbycusis base is 38 decibels. Yet adding the NIPTS of the combined Passchier-Vermeer data to the presbycusis data of Baughn would estimate that the resulting NHTL(.1) from an average sound level of 95 dB would be 51.3 decibels. This is, of course, in almost perfect agreement with the 50.9 decibels predicted directly by Baughn's data. This same agreement generally holds for other percentiles and for other exposures. The exception is that for 4000 Hz, when Baughn's HTL values are above 50 dB and especially above 60 dB, the addition of NIPTS from Robinson and Passchier-Vermeer combined data definitely begin to overestimate the actual NHTL of Baughn's data when combined with Baughn's presbycusis base. This is why the caveats with respect to NHTL above 50 decibels. Thus, the use of Baughn's data provides the basis of a key finding. It is reasonable to add the combined NIPTS data of Passchier-Vermeer and Robinson to any presbycusis base providing the resulting Noise Impacted Hearing Threshold Level is 50 decibels or lower.

Further support of this statement comes from the NIOSH report.[6] The authors were able to conclude that older employees exposed to noise for the first time were at least as sensitive, if not more sensitive, to noise exposure than employees who began their noise exposure at age 20 or there abouts. Again, this is consistent with the notion that the NIPTS calculated from a good hearing population can also be added to a poorer hearing population.

With respect to adding NIPTS to the 10th percentile and 90th percentile, the question often arises as to whether or not simple addition is proper. Especially bothersome to many is when NIPTS(.1) is considerably larger than NIPTS(.9). This would seem to imply that individuals with greater hearing loss are more susceptible to noise. This is not necessarily the case, however. It again must be remembered that NIPTS as used in this report describes changes in statistical distributions of hearing level due to noise. The statistical distribution of noise induced hearing changes of individuals is not described. However, if the assumption that susceptibility to hearing loss is independent of initial hearing level is used, Theissen has shown that adding a skewed[16] distribution of individual hearing loss to a normal distribution of hearing level threshold will always result in a skewed distribution of NHTL.[17] This means that NIPTS(.1) value will be greater than the values of NIPTS(.9) or the median. Using several different, but reasonable, skewed distributions, Johnson has shown that this effect should also be valid for reasonable non-normal distributions. While such modeling does not prove that NIPTS can be added to any presbycusis level, it does show that such a simple addition is not unreasonable. Baughn's data show that such a simple addition is not only not unreasonable, but is probably the best procedure to use at this time.

15. DEVELOPMENT OF TABLES THAT SHOW THE PERCENTAGE OF THE POPULATION EXPECTED TO EXCEED A SPECIFIED HEARING THRESHOLD LEVEL.

APPROACH

Noise Impacted Hearing Threshold Level (NHTL) is plotted on probability paper for the 10th, 50th and the 90th percentiles. A straight line is drawn through the 10th and 50th percentile points [NHTL(.1) and NHTL(.5)] and extended to the 1st percentile [(NHTL(.01)]. Similarly, a line is drawn through the 50th and 90th percentile and extended through the 99th percentile. The percentage that have hearing threshold levels greater than some specified value (or fence) is determined by the intersection of that level with one of the two straight lines drawn. See Figure 3 for an example: this can also be done by a simple computer program and tables 12, 13, and 14 were all done by a computer program instead of graphically. The computer program used is described in an appendix to this report.

SAMPLE CALCULATIONS

Calculate the number of 50 year old women that would be expected to have hearing threshold levels greater than 25 decibels for the combined frequencies of 1/4(.5, 1, 2, 3) kHz. The noise exposure is an average sound level of 90 decibels for 30 years. Using data from table 5 and the corrected data of table 7, NHTL(.1) is calculated as 9.0 dB plus 20 dB or 29.0 decibels. NHTL(.5) is also calculated as 5.0 dB plus 7.3 dB or 12.3 decibels. These values are plotted in figure 3 and a line is drawn through these points. The intersection of the 25 decibel fence with this line is at the point where 83 percent of the population have better hearing. Reading the scale along the top of the paper shows between 17 percent of the population have worse hearing (or higher threshold levels). This is desired information. This value is shown in table 13. Note: the graphic method is a little less accurate and for this reason the computer technique was used to generate tables 12-14.

DISCUSSION

The above procedure is straightforward and quite flexible. Other fences besides one of 25 dB can be used and the reader is encouraged to observe the effect of using different fences in figure 3.

16. DEVELOPMENT OF TABLES THAT SHOW THE NUMBER OF DECIBELS ABOVE 25 DECIBELS FOR 1/4(.5, 1, 2, 3) kHz THAT WOULD OCCUR IN A POPULATION OF 100 INDIVIDUALS (UNITS OF POTENTIAL COMPENSATION).

APPROACH

The data are plotted in the same manner as in the preceding section for calculating the percentage of the population exceeding some hearing threshold level. Thus figure 3 is replicated. Using the scale at the top of the paper, the hearing levels indicated by the NHTL line for the .5, 1.5, 2.5, etc., percentiles are calculated until the hearing level is below the 25 decibel fence. For the hearing levels above the 25 decibel fence, 25 decibels are substracted from each level and then the resultant levels are summed. This value provides the number of Units of Potential Compensation. In summary, Units of Potential Compensation is the normalized area between the NHTL curves and the 25 decibel fence. Tables 15, 16, and 17 provides Units of Potential Compensation for 1/4(.5, 1, 2) kHz with a 25 decibel fence for the presbycusis base of tables 7, 8, or 9.

A computer program was developed to make these calculations. This program is available in Appendix A. For the sake of consistency, this program was used to generate tables 15, 16, and 17. In this program, calculations were made every 0.2 percentiles (i.e. .1, .3, .5, .7, .9, 1.1, etc) and the final answer divided by 5.

SAMPLE CALCULATION

Calculate the Units of Potential Compensation to be expected in a group of 50 year old females with no occupational noise exposure.

The necessary data are already plotted in Figure 3 (see last section for details). Using the curve marked presbycusis, the percentiles at the top of the figure are used at .5, 1.5, etc. Specifically:

Percentile	HTL	HTL-25
.5	32.6	7.6
1.5	28.7	3.7
2.5	26.5	1.5
3.5	25.0	0
		12.8

Thus, the Units of Potential Compensation calculated in this manner equals ≈ 13 units per 100 people. In table 16, the Units of Potential Compensation was 15 units per 100 people. The small difference is to the slight improvement in accuracy in using smaller increments.

DISCUSSION

The above procedure provides an approximate estimate of the relative magnitude of the impact of different noise exposures. Since the PHS data used are for the better ear, this procedure should provide a good estimate of possible compensation costs since the dollar amount of compensation is more dependent (usually 5 times) on the better ear than the worse ear. Obviously, the entire procedure is not perfectly accurate, and probably never will be. Slight errors occur by assuming parts of the distribution are normal. This might introduce a significant error for the worst hearing 5-10 percent of the population. Again refer to figure 1. On the other hand, part of this poor hearing is caused by factors that can be easily identified as not being caused by noise. Thus not all these cases would be provided compensation for noise exposure. Likewise, for the more intense noise exposures, the Noise Impacted Hearing Threshold Level often exceeded

70 decibels. Yet in the calculation of Units of Potential Compensation, no correction was made for this fact. These latter two considerations should more than compensate for any errors associated with assuming a normal curve. As stated before, however, the greatest source of error will probably be in the presbycusis base itself. The truth should always be somewhere between the values of table 15 and table 17.

17. APPLICATION OF PRECEDING PROCEDURES TO OTHER DATA BASES

APPROACH AND DISCUSSION

The preceding procedures such as those used to obtain tables 12-17 can be used for any reasonable presbycusis data base. Recently, there have been several more presbycusis data bases proposed. One report by Robinson and Sutton[19] synthesizes many data bases into two common bases: one for otologically screened men and one for otologically screened women. This data are presented in table 18. For convenience, tables of the percentage of the population expected to exceed 25 decibels (tables 19 and 20) are provided as well as tables of potential compensation (tables 21 and 22). Royster and Thomas have obtained uncreened data that are typical for a certain geographic region.[20] These data are also presented in table 23. The Royster and Thomas data indicate that there may be some inconsistencies in the male data for the older ages. This problem, which is most likely due to the small sample size in the older age groups (actually only 24 subjects were in the 50-59 age group and 14 in the 60-69 group), highlights several considerations. First, small data bases are sometimes difficult to use without some type of smoothing to make the data fit into a logical pattern of presbycusis. Second, if given the problem of estimating the effect of noise on unscreened populations typical of the population used in the Royster et al. study, then data such as that in table 23 are useful for selecting which presbycusis base (those of table 7, table 8, table 9 or table 18) best represents the population in question. In this example, the male data in table 23 might best be represented by table 8 and the female data in table 23 by table 7. Then the NIPTS in table 5 could be added to table 8 and 7 to predict the resulting Noise Induced Hearing Threshold Levels.

Finally, most of the difficulty with the data in table 23 is with the .9 and .1 percentiles. The median is consistent. Thus a practical approach that could be taken is to use the differences in HTL(.1) and HTL(.5) in some table such as table 7 to predict the HTL(.1) that might be expected from the median in table 23. For instance, for women of age 50 (table 7) the difference between HTL(.1) and HTL(.5) at 4000 Hz is 17 dB (26-9). Adding 17 dB to the median in table 23 (13.6 dB) would predict HTL(.1) to be 31 dB. Thus, this procedure could be used to modify the HTL(.9) and HTL(.1) values of table 23 to be consistent with those in table 7.

18. DERIVATION OF A MODIFIED PRESBYCUSIS BASE THAT REASONABLY PREDICTS THE SAME PERCENTAGE OF THE POPULATION EXCEEDING 25 DECIBELS FOR 1/3 (.5, 1, 2 kHz) AS ISO STANDARD 1999

APPROACH AND DISCUSSION

The data in reference 5 (specifically table 7 of reference 5) have been used as the basis of ISO standard 1999. These data, which are presented as the percent of the population that will exceed a 25 decibel hearing level versus noise exposure level, have been criticized as being unrealistic. A smaller percent of the population is normally found to exceed 25 decibels than predicted by ISO 1999. Therefore, it is informative to investigate the reason for this discrepancy. Table 24 provides the basic presbycusis data that are obtainable by Baughn's report (ref 5). These data are the hearing levels of a group of workers exposed to an A-weighted average level of 78 dB during the working day (see ref 5 for statistical breakout of the noise). Also included in table 24 is a presbycusis base that would provide an adequate prediction of Baughn's Risk Data (table 7 of Baughn's report) if the NIPTS data in table 5 were added to this unscreened presbycusis base. A comparison of the data in table 7 of Baughn's report with that using the recommended presbycusis base and the NIPTS data in table 5 is provided in table 25. The recommended presbycusis base for Baughn's data was derived by trial and error until the data shown in table 25 showed reasonable correspondence. While the fit is not perfect, it is quite good. The good agreement between the recommended presbycusis base and the actual data from table 3 of reference 5 should be noted. In the final analysis, not too much accuracy is lost if the NIPTS data in table 5 were added to the actual hearing threshold levels provided by Baughn (table 3 of Baughn's report). Nevertheless, the recommended presbycusis base of table 24 is preferred and tables 26 and 27 were derived from this data base.

The percent of population with losses above 25 dB and the Units of Potential Compensation are shown in tables 26 and 27 respectively. Thus table 27 provided Units of Potential Compensation that are consistent with the present ISO standard R-1999.

When compared to tables 8 or 9, the data in table 24 show considerably higher hearing threshold levels, especially for the median and the .9 percentile, than either table 8 or 9. These elevated threshold levels, not the NIPTS data derived from Baughn's study, cause the tables in R-1999 to overestimate the percentage of the population that exceed 25 decibels for many of the specific populations in the world.

This again emphasizes the need for determining the presbycusis base of the population being studied.

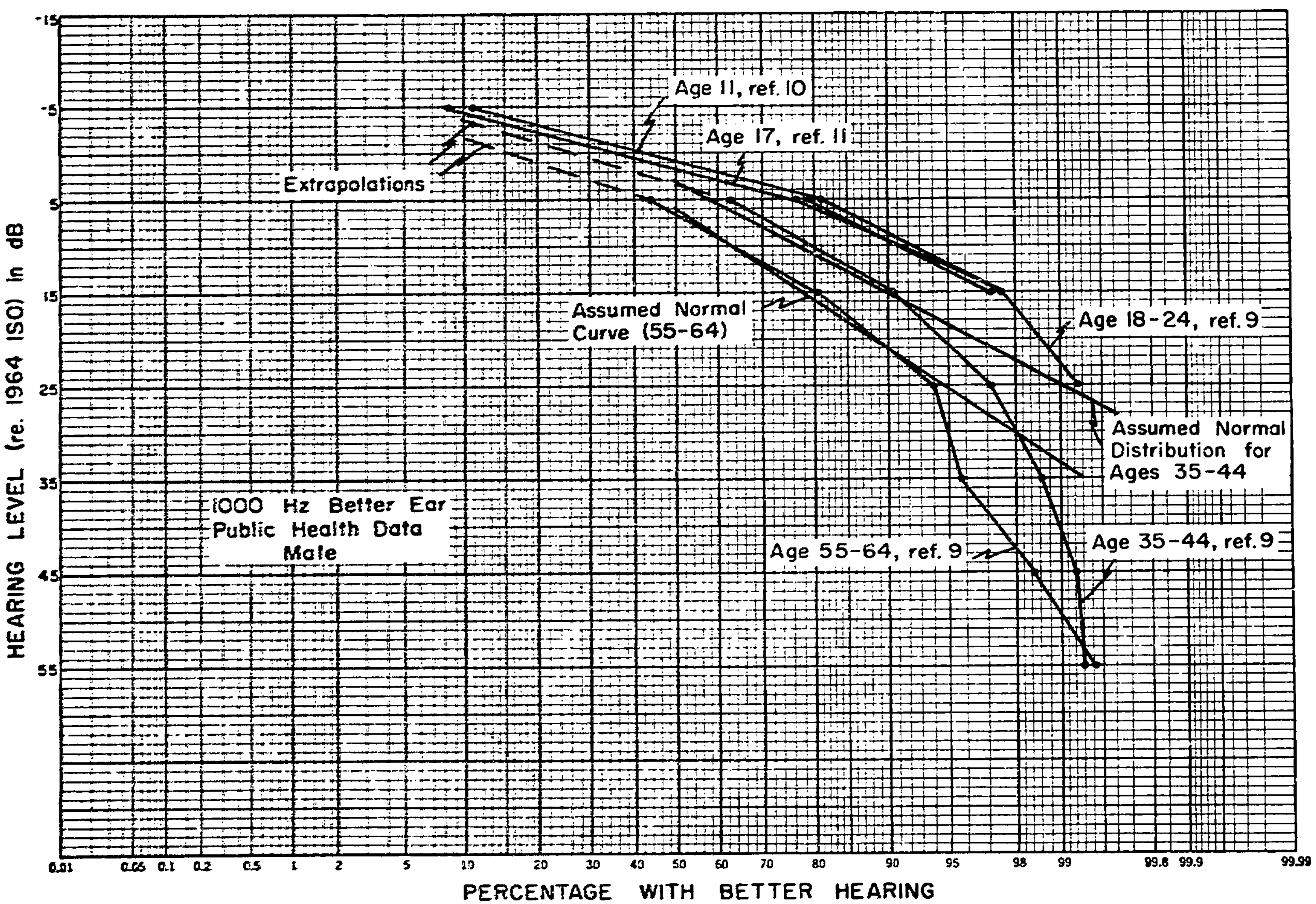


Figure 1. Outline of Graphic Procedures Used to Estimate HTL(.1), HTL(.5), and HTL(.9)

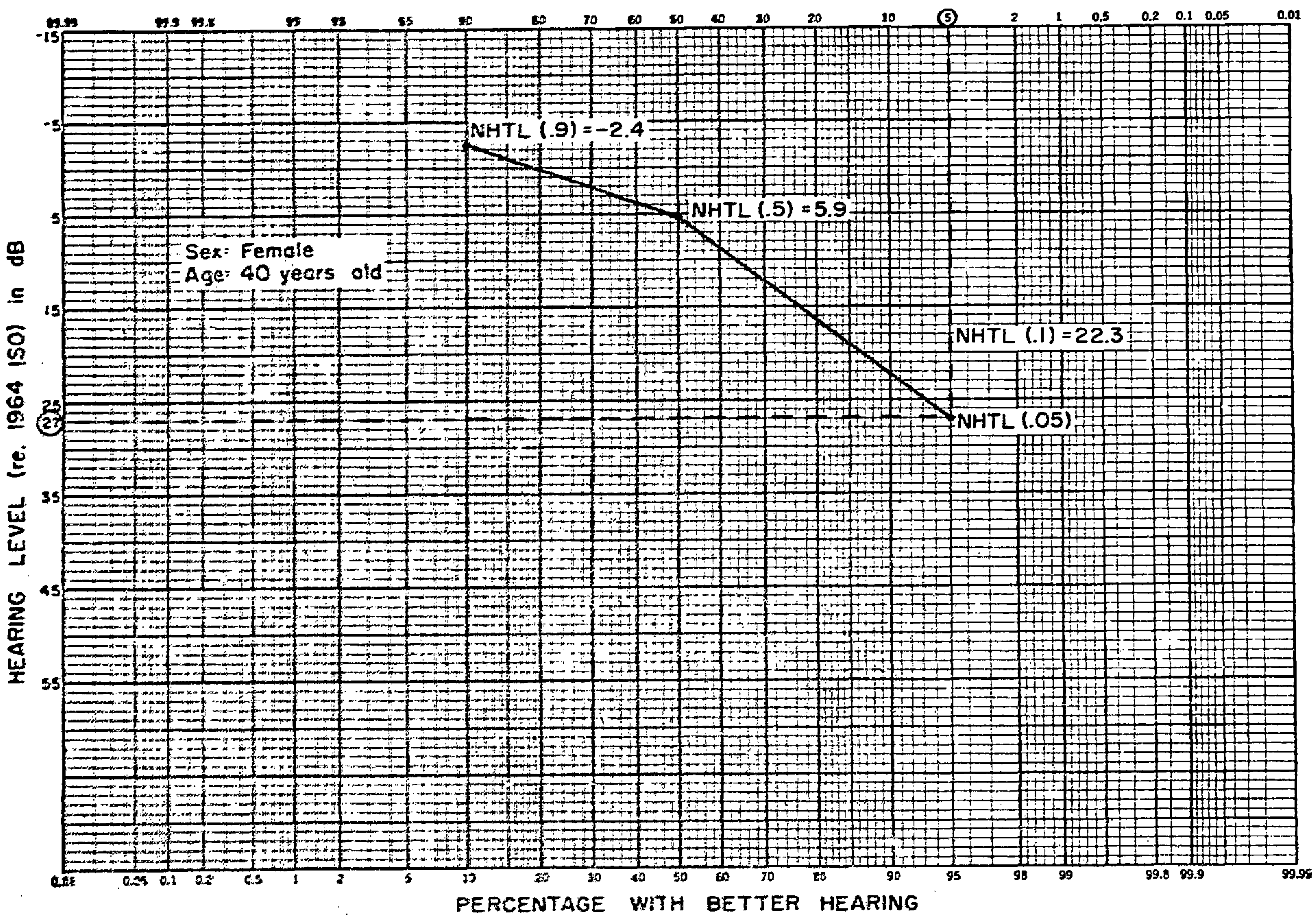


Figure 2. Sample Calculations: Expected Hearing Levels at 2 kHz for HTL(.05)

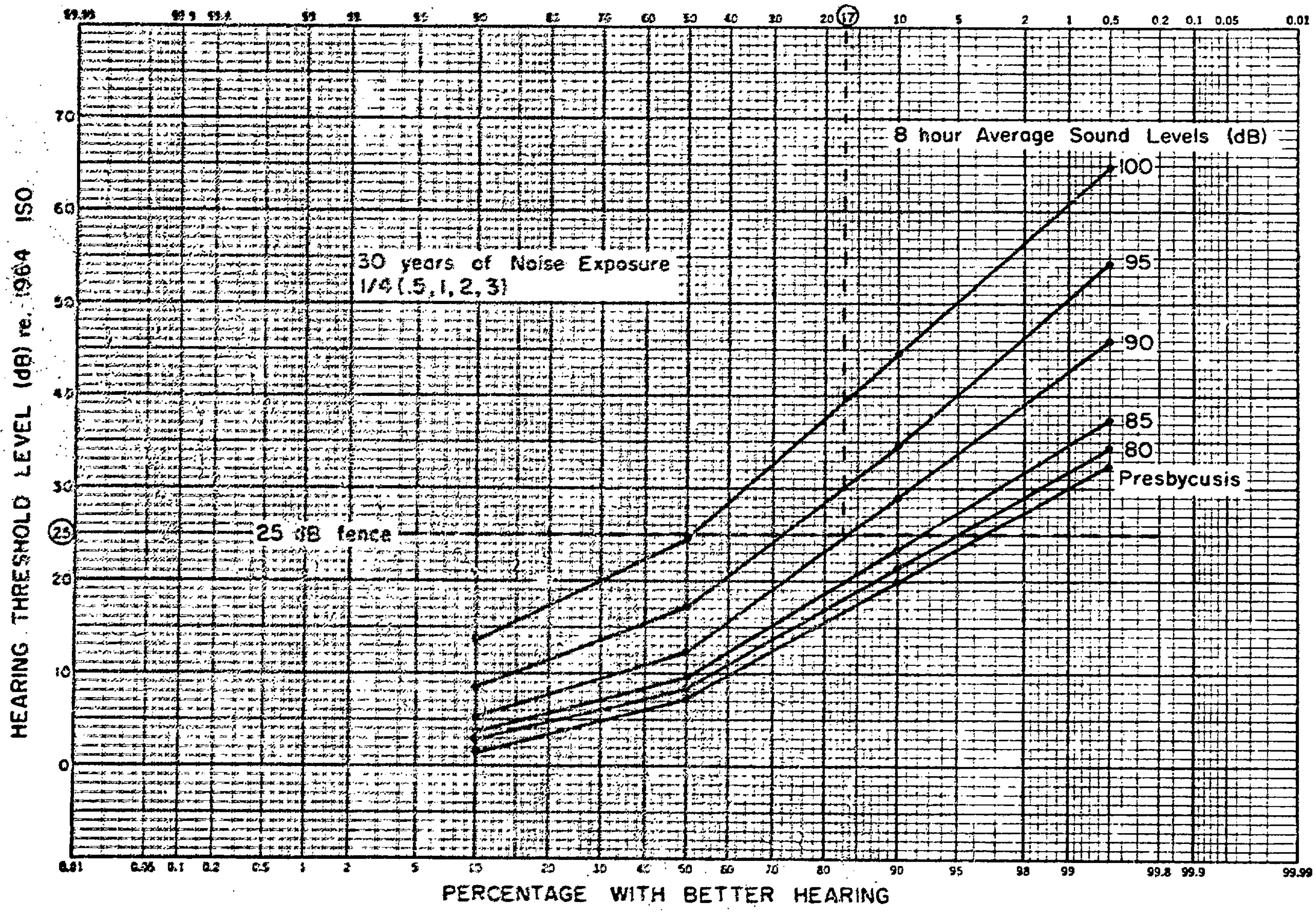


Figure 3. Graph of hearing levels for women at age 50 with 30 years of exposure to noise levels from 75 to 100 dB. Presbycusis data are from the 1960-62 Public Health Survey and are an average of 500 Hz, 1000 Hz, 2000 Hz, and 3000 Hz.

Table 1

The Noise Induced Permanent Threshold Shift predicted by Passchier-Vermeer (ref. 3) for average sound levels of 75 to 100 dB. Data are for 8-hour occupational noise exposures. Medians (.5) are from table A-1 and the 90th (.9) and the 10th (.1) percentiles are from table B-5 of ref. 3.

Sound Level	*Freq.*	*10 yrs.*			*20 yrs.*			*30 yrs.*			*40 yrs.*		
		.9	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.8*	*.5*	*.1*
[dB]	*[Hz]*												
75	500	0	0	0	0	0	0	0	0	0	0	0	0
80	500	0	0	.8	0	0	0	.6	0	0	1.4	0	0
85	500	0	0	1.7	0	0	.9	.6	0	.1	1.4	0	0
90	500	0	0	2.3	0	0	1.5	.6	0	.7	1.4	0	0
95	500	0	0	2.3	0	0	1.5	0	0	.7	.6	0	0
100	500	2.2	4.3	6.6	3.7	5.2	6.7	5.2	6.1	6.8	6.9	7.0	6.9

Sound Level	*Freq.*	*10 yrs.*			*20 yrs.*			*30 yrs.*			*40 yrs.*		
		.9	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*
[dB]	*[Hz]*												
75	1000	0	0	0	0	0	0	0	0	0	0	0	0
80	1000	0	0	.8	0	0	0	.6	0	0	1.4	0	0
85	1000	0	0	2.3	0	0	1.5	.6	0	.7	1.4	0	0
90	1000	0	0	2.3	0	0	1.5	.6	0	.7	1.4	0	0
95	1000	0	2.5	4.8	0	3.3	4.8	4.7	4.1	4.8	6.3	4.9	4.8
100	1000	4.2	6.8	9.6	6.6	8.6	10.6	9.0	10.4	11.6	12.2	12.2	12.6

Sound Level	*Freq.*	*10 yrs.*			*20 yrs.*			*30 yrs.*			*40 yrs.*		
		.9	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*
[dB]	*[Hz]*												
75	2000	0	0	0	0	0	0	0	0	0	0	0	0
80	2000	0	0	1.8	0	0	0	1.8	0	0	3.2	0	0
85	2000	0	.3	6.1	.6	.6	4.6	2.7	.9	2.9	4.4	1.2	.8
90	2000	0	1.7	8.5	1.4	3.4	8.4	4.9	5.1	11.1	8.1	6.9	7.5
95	2000	0	4.8	14.6	4.0	9.0	17.0	10.3	13.5	19.5	16.2	18.0	21.6
100	2000	0	7.3	21.1	6.5	14.5	26.5	15.8	22.0	32.0	24.2	29.0	36.6

Sound Level	*Freq.*	*10 yrs.*			*20 yrs.*			*30 yrs.*			*40 yrs.*		
		.9	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*
[dB]	*[Hz]*												
75	3000	0	0	0	0	0	0	0	0	0	0	0	0
80	3000	0	3.0	5.7	3.3	3.3	3.3	6.3	3.6	1.2	9.5	3.9	0
85	3000	2.1	6.1	8.8	5.7	6.7	6.7	9.0	7.3	4.9	12.5	7.9	2.9
90	3000	5.5	12.5	20.7	9.7	13.7	19.2	12.7	15.0	17.9	17.8	16.2	16.7
95	3000	11.5	21.0	32.2	16.6	23.1	32.6	21.4	25.2	32.3	26.4	27.3	31.8
100	3000	22.8	32.3	44.5	29.2	35.7	45.2	35.1	38.9	46.0	41.2	42.1	46.6

Sound Level	*Freq.*	*10 yrs.*			*20 yrs.*			*30 yrs.*			*40 yrs.*		
		.9	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*
[dB]	*[Hz]*												
75	4000	0	0	0	0	0	0	0	0	0	0	0	0
80	4000	0	5.0	7	0	5.0	0	2.7	5.0	7.6	5.6	5.0	5.0
85	4000	1.8	9.8	16.5	4.8	9.8	13.8	7.5	9.8	11.4	10.4	9.8	8.8
90	4000	9.5	16.5	22.7	12.5	16.5	20.0	15.2	16.5	17.6	18.1	16.5	15.0
95	4000	21.4	27.4	32.1	24.4	27.4	29.4	27.1	27.4	27.0	30.0	27.4	24.4
100	4000	33.7	38.7	42.5	36.7	38.7	39.7	39.4	38.7	37.3	42.3	38.7	34.7

Sound Level [dB]	Freq. [Hz]	10 yrs. .9	10 yrs. .5	10 yrs. .1	20 yrs. .9	20 yrs. .5	20 yrs. .1	30 yrs. .9	30 yrs. .5	30 yrs. .1	40 yrs. .9	40 yrs. .5	40 yrs. .1
75	6000	0	0	0	0	0	0	0	0	0	0	0	0
80	6000	.1	3.1	5.8	3.1	3.1	3.1	5.8	3.1	.7	8.6	3.1	0
85	6000	1.1	7.1	11.8	4.1	7.1	9.1	6.8	7.1	6.7	9.7	7.1	4.1
90	6000	1.6	11.6	19.3	4.6	11.6	16.6	7.3	11.6	14.2	10.2	11.6	11.6
95	6000	4.3	17.3	27.0	7.5	17.5	24.5	10.3	17.6	22.2	13.3	17.7	19.7
100	6000	10.6	23.6	35.3	15.8	25.8	34.8	20.6	28.1	34.7	25.9	30.3	34.3

Table 2

The Noise Induced Permanent Threshold Shift predicted by averaging the data of Robinson (ref. 1) for average sound levels of 75 to 100 dB. Data are for 8-hour occupational noise exposures.

Sound Level [dB]	*Freq. [Hz]*	*10 yrs.* *.9*	*.5*	*.1*	*20 yrs.* *.9*	*.5*	*.1*	*30 yrs.* *.9*	*.5*	*.1*	*40 yrs.* *.9*	*.5*	*.1*
75	500	0	0	0	0	0	0	0	0	0	0	0	0
80	500	0	.2	.3	.1	.2	.5	.1	.2	.7	.1	.3	.8
85	500	.1	.4	1.0	.2	.6	1.5	.3	.7	2.0	.3	.8	2.2
90	500	.3	.9	2.3	.4	1.3	3.3	.6	1.6	4.3	.7	1.9	4.8
95	500	.6	1.8	4.6	.9	2.6	6.5	1.2	3.3	8.2	1.4	3.7	9.2
100	500	1.2	3.5	8.5	1.9	5.0	11.7	2.5	6.3	14.4	2.8	7.3	15.8

Sound Level (dB)	*Freq.* (Hz)	*10 yrs.* *.9*	*.5*	*.1*	*20 yrs.* *.9*	*.5*	*.1*	*30 yrs.* *.9*	*.5*	*.1*	*40 yrs.* *.9*	*.5*	*.1*
75	1000	0	0	0	0	0	0	0	0	0	0	0	0
80	1000	.1	.2	.5	.1	.3	.8	.1	.4	1.1	.1	.4	1.2
85	1000	.2	.6	1.6	.3	.9	2.3	.4	1.2	3.0	.5	1.3	3.4
90	1000	.5	1.4	3.5	.8	2.0	5.0	.9	2.6	6.4	1.1	2.9	7.1
95	1000	1.0	2.8	6.9	1.5	4.0	9.6	1.9	5.1	11.9	2.2	5.7	13.0
100	1000	2.0	5.3	12.4	3.0	7.5	16.4	3.8	9.4	19.5	4.3	10.4	21.1

Sound Level [dB]	*Freq. [Hz]*	*10 yrs.* *.9*	*.5*	*.1*	*20 yrs.* *.9*	*.5*	*.1*	*30 yrs.* *.9*	*.5*	*.1*	*40 yrs.* *.9*	*.5*	*.1*
75	2000	0	0	0	0	0	0	0	0	0	0	0	0
80	2000	.2	.5	1.3	.2	.7	1.8	.3	.9	2.3	.4	1.1	2.6
85	2000	.5	1.4	3.6	.7	2.0	5.0	.9	2.6	6.2	1.1	2.9	7.0
90	2000	1.1	3.1	7.5	1.7	4.4	10.2	2.2	5.6	12.4	2.5	6.3	13.6
95	2000	2.4	6.1	13.7	3.4	8.4	17.7	4.4	10.5	20.6	5.0	11.6	22.1
100	2000	4.6	11.0	21.9	6.5	14.7	26.7	8.2	17.7	29.7	9.2	19.2	31.1

Sound Level [dB]	*Freq. [Hz]*	*10 yrs.* *.9*	*.5*	*.1*	*20 yrs.* *.9*	*.5*	*.1*	*30 yrs.* *.9*	*.5*	*.1*	*40 yrs.* *.9*	*.5*	*.1*
75	3000	0	0	0	0	0	0	0	0	0	0	0	0
80	300	.4	.9	2.5	.5	1.4	3.4	.6	1.8	4.1	.7	2.0	4.6
85	3000	1.0	2.7	6.6	1.5	3.9	8.9	1.9	5.0	10.5	2.2	5.5	11.4
90	3000	2.3	5.9	13.0	3.4	8.2	16.5	4.3	10.1	18.9	4.8	11.1	20.1
95	3000	4.6	11.0	21.4	6.6	14.7	25.6	8.3	17.5	27.9	9.2	18.9	29.1
100	3000	8.7	18.4	30.4	11.9	23.2	34.1	14.5	26.4	35.9	15.9	27.9	36.6

Sound Level [dB]	*Freq. [Hz]*	*10 yrs.* *.9*	*.5*	*.1*	*20 yrs.* *.9*	*.5*	*.1*	*30 yrs.* *.9*	*.5*	*.1*	*40 yrs.* *.9*	*.5*	*.1*
75	4000	0	0	0	0	0	0	0	0	0	0	0	0
80	4000	.5	1.2	3.1	.6	1.8	4.1	.9	2.3	5.0	1.0	2.5	5.5
85	4000	1.4	3.5	8.1	1.9	5.0	10.5	2.5	6.1	12.3	2.9	6.8	13.1
90	4000	3.0	7.3	15.4	4.3	10.1	18.9	5.4	12.2	21.1	6.1	13.3	22.2
95	4000	5.9	13.4	24.2	8.3	17.5	27.9	10.3	20.4	29.9	11.4	21.8	30.7
100	4000	10.8	21.6	33.0	14.5	26.4	35.9	17.4	29.4	37.0	18.9	30.8	37.4

Sound Level [dB]	*Freq. [Hz]*	*10 yrs.* .9	.5	.1	*20 yrs.* .9	.5	.1	*30 yrs.* .9	.5	.1	*40 yrs.* .9	.5	.1
75	6000	0	0	0	0	0	0	0	0	0	0	0	0
80	6000	.4	.9	2.2	.5	1.2	3.1	.6	1.6	3.7	.6	1.8	4.1
85	6000	1.0	2.5	5.9	1.4	3.5	8.1	1.7	4.4	9.6	1.9	5.0	10.5
90	6000	2.1	5.3	11.8	3.0	7.3	15.4	3.8	9.1	17.7	4.3	10.1	18.9
95	6000	4.2	10.0	19.9	5.9	13.4	24.2	7.4	16.0	26.8	8.3	17.5	27.9
100	6000	7.8	16.9	29.0	10.8	21.6	33.0	13.1	24.8	35.0	14.5	26.4	35.9

Table 3

The Noise Induced Permanent Threshold Shift predicted by averaging the data of Robinson and Passchier-Vermeer for average sound levels of 75 dB* to 100 dB. Data is for 8 hour occupational noise exposures.

Sound Level [dB]	*Freq. [Hz]*	*10 yrs.* .9	*10 yrs.* .5	*10 yrs.* .1	*20 yr.s* .9	*20 yr.s* .5	*20 yr.s* .1	*30 yrs.* .9	*30 yrs.* .5	*30 yrs.* .1	*40 yrs.* .9	*40 yrs.* .5	*40 yrs.* .1
75	500	0	0	0	0	0	0	0	0	0	0	0	0
80	500	0	.1	.6	.1	.1	.3	.4	.1	.4	.8	.2	.4
85	500	.1	.2	1.4	.1	.3	1.2	.5	.7	1.5	.9	.4	1.1
90	500	.2	.5	2.3	.2	.7	2.4	.6	.8	2.5	1.1	1.0	2.4
95	500	.3	.9	3.5	.5	1.3	4.0	.6	1.7	4.5	1.0	1.9	4.6
100	500	1.7	3.9	7.6	2.8	5.1	9.2	3.9	6.2	10.6	4.9	7.2	11.4

Sound Level [dB]	*Freq. [Hz]*	*10 yrs.* .9	*10 yrs.* .5	*10 yrs.* .1	*20 yrs.* .9	*20 yrs.* .5	*20 yrs.* .1	*30 yrs.* .9	*30 yrs.* .5	*30 yrs.* .1	*40 yrs.* .9	*40 yrs.* .5	*40 yrs.* .1
75	1000	0	0	0	0	0	0	0	0	0	0	0	0
80	1000	.1	.1	.7	.1	.2	.4	.4	.2	.6	.8	.2	.6
85	1000	.1	.3	2.0	.2	.5	1.9	.5	.6	1.9	.9	.7	1.7
90	1000	.3	.7	2.9	.4	1.0	3.3	.8	1.3	3.6	1.3	1.5	3.6
95	1000	.5	2.7	5.9	.8	3.7	7.2	3.3	4.6	8.4	4.3	5.3	8.9
100	1000	3.1	6.1	11.0	4.8	8.1	13.5	6.4	9.9	15.6	8.3	11.3	16.9

Sound Level [dB]	*Freq. [Hz]*	*10 yrs.* .9	*10 yrs.* .5	*10 yrs.* .1	*20 yrs.* .9	*20 yrs.* .5	*20 yrs.* .1	*30 yrs.* .9	*30 yrs.* .5	*30 yrs.* .1	*40 yrs.* .9	*40 yrs.* .5	*40 yrs.* .1
75	2000	0	0	0	0	0	0	0	0	0	0	0	0
80	2000	.1	.3	1.6	.1	.4	.9	1.1	.5	1.2	1.8	.6	1.3
85	2000	.3	.9	4.9	.7	1.3	4.8	1.8	1.8	4.6	2.8	2.1	3.9
90	2000	.6	2.4	8.0	1.6	3.9	9.3	3.6	5.4	11.8	5.3	6.6	10.6
95	2000	1.2	5.5	14.2	3.7	8.7	17.4	7.4	12.0	20.1	10.6	14.8	21.9
100	2000	2.3	9.2	21.5	6.5	14.6	26.6	12.0	19.9	30.9	16.7	24.1	33.9

*For broad band noise the NIPTS for 75 dB is expected to be negligible as indicated by the zeros in the table. However, long exposure to pure tones or narrow bands (1/3 octave band or narrower) at 75 dB could result in a small amount of NIPTS in the audiometric frequencies located slightly above the exposure frequencies.

Sound Level [dB]	*Freq. [Hz]*	*10 yrs.* .9	*10 yrs.* .5	*10 yrs.* .1	*20 yrs.* .9	*20 yrs.* .5	*20 yrs.* .1	*30 yrs.* .9	*30 yrs.* .5	*30 yrs.* .1	*40 yrs.* .9	*40 yrs.* .5	*40 yrs.* .1
75	3000	0	0	0	0	0	0	0	0	0	0	0	0
80	3000	.2	2.0	4.1	1.9	2.4	3.4	3.5	2.7	2.7	5.1	3.0	2.3
85	3000	1.6	4.4	7.7	3.6	5.3	7.8	5.5	6.2	7.6	7.4	6.7	7.2
90	3000	3.9	9.2	16.9	6.6	11.0	17.9	8.5	12.6	18.4	11.3	13.7	18.4
95	3000	8.1	16.0	26.8	11.6	18.9	29.1	14.9	21.4	30.1	17.8	23.1	30.5
100	3000	15.8	25.4	37.5	20.6	29.5	39.7	24.8	32.7	41.0	28.6	35.0	41.6

Sound Level [dB]	Freq. [Hz]	10 yrs. .9	10 yrs. .5	10 yrs. .1	20 yrs. .9	20 yrs. .5	20 yrs. .1	30 yrs. .9	30 yrs. .5	30 yrs. .1	40 yrs. .9	40 yrs. .5	40 yrs. .1
75	4000	0	0	0	0	0	0	0	0	0	0	0	0
80	4000	.3	3.1	1.9	.3	3.4	2.1	1.8	3.7	6.3	3.3	3.8	5.3
85	4000	1.6	6.7	12.3	3.4	7.4	12.2	5.0	8.0	11.9	6.7	8.3	11.0
90	4000	6.3	11.9	19.1	8.4	13.3	19.5	10.3	14.4	19.4	12.1	14.9	18.6
95	4000	13.7	20.4	28.2	16.4	22.5	28.7	18.7	23.9	28.5	20.7	24.6	27.6
100	4000	22.3	30.2	37.8	25.6	32.6	37.8	28.4	34.1	37.2	30.6	34.8	36.1

Sound Level [dB]	Freq. [Hz]	10 yrs. .9	10 yrs. .5	10 yrs. .1	20 yrs. .9	20 yrs. .5	20 yrs. .1	30 yrs. .9	30 yrs. .5	30 yrs. .1	40 yrs. .9	40 yrs. .5	40 yrs. .1
75	6000	0	0	0	0	0	0	0	0	0	0	0	0
80	6000	.3	2.0	4.0	1.8	2.2	3.1	3.2	2.4	2.2	4.6	2.5	2.1
85	6000	1.1	4.8	8.9	2.8	5.3	8.6	4.3	5.8	8.2	5.8	6.1	7.3
90	6000	1.9	8.5	15.6	3.8	9.5	16.0	5.6	10.4	16.0	7.3	10.9	15.3
95	6000	4.3	13.7	23.5	6.7	15.5	24.4	8.9	16.8	24.5	10.8	17.6	23.8
100	6000	9.2	20.3	32.2	13.3	23.7	33.9	17.0	26.5	34.9	20.2	28.4	35.1

Table 4

NIPTS calculated from comparison of Passchier-Vermeer and Robinson's data to NIPTS calculated from Baughn for the average of .5 KHz, 1 KHz, and 2 KHz after 40 years exposure (from reference 8).

Exposure Level	*Passchier-Vermeer*	*Robinson*	*average of Passchier-Vermeer & Robinson*	*Baughn*
NIPTS(.1)	.3	4.2	2.2	3.9
85 dB NIPTS(.5)	.4	1.7	1.1	1.9
NIPTS(.9)	2.4	.6	1.5	1.2
NIPTS(.1)	2.5	8.5	5.5	7.3
90 dB NIPTS(.5)	2.3	3.7	3.0	3.2
NIPTS(.9)	3.6	1.5	2.6	2.5
NIPTS(.1)	8.8	14.8	11.8	12.9
95 dB NIPTS(.5)	7.6	7.0	7.3	6.1
NIPTS(.9)	7.7	2.9	5.3	4.1

Table 5

The Noise Induced Permanent Threshold Shift for combined frequencies predicted by averaging the data of Robinson and Passchier-Vermeer for average sound levels of 75 to 100 dB. Data are for 8-hour occupational noise exposures. The 90th, 50th, and 10th percentiles are indicated by .9, .5, and .1.

Sound Level [dB]	*10 yrs.* .9	*10 yrs.* .5	*10 yrs.* .1	*20 yrs.* .9	*20 yrs.* .5	*20 yrs.* .1	*30 yrs.* .9	*30 yrs.* .5	*30 yrs.* .1	*40 yrs.* .9	*40 yrs.* .5	*40 yrs.* .1
					¼(.5,1,2,3)							
75	0	0	0	0	0	0	0	0	0	0	0	0
80	.1	.6	1.4	.6	.8	1.4	1.4	.9	1.4	2.1	1.0	1.4
85	.5	1.5	3.8	1.2	1.9	3.8	2.1	2.3	3.8	3.0	2.5	3.8
90	1.3	3.2	7.5	2.2	4.2	8.2	3.4	5.0	9.0	4.8	5.7	9.0
95	2.5	6.3	12.6	4.2	8.2	14.4	6.6	9.9	15.8	8.4	11.3	16.5
100	5.7	11.2	19.4	8.7	14.[illegible]	22.3	11.8	17.2	24.5	14.6	19.4	26.0
					⅓(.5,1,2)							
75	0	0	0	0	0	0	0	0	0	0	0	0
80	.1	.2	.7	.1	.2	.7	.6	.3	.7	1.1	.3	.8
85	.2	.5	2.6	.3	.7	2.6	.9	1.0	2.6	1.5	1.1	2.6
90	.4	1.2	4.4	.7	1.9	5.0	1.7	2.5	5.8	2.6	3.0	5.8
95	.7	3.0	7.9	1.7	4.6	9.5	3.8	6.1	11.0	5.3	7.3	11.8
100	2.4	6.4	13.4	4.7	9.3	16.4	7.4	12.0	19.0	10.0	14.2	20.7
					¼(.5,1,2,4)							
75	0	0	0	0	0	0	0	0	0	0	0	0
80	.1	.9	1.1	.2	1.0	1.1	.9	1.1	2.0	1.7	1.2	2.0
85	.5	2.0	5.0	1.1	2.4	5.0	2.0	2.8	5.0	2.8	2.9	5.0
90	1.9	3.9	8.1	2.7	4.7	8.6	3.8	5.5	9.1	5.0	6.0	9.1
95	3.9	7.4	13.0	5.4	9.1	14.3	7.5	10.6	15.4	9.2	11.7	15.8
100	7.4	12.4	19.5	9.9	15.1	21.8	12.7	17.5	23.6	15.1	19.4	24.6
					⅓(1,2,3)							
75	0	0	0	0	0	0	0	0	0	0	0	0
80	.1	.8	4.5	.7	1.0	1.6	1.7	1.1	1.5	2.6	1.3	1.4
85	.7	1.9	4.9	1.5	2.4	4.8	2.6	2.9	4.7	3.7	3.2	4.3
90	1.6	4.1	9.3	2.9	5.3	10.2	4.3	6.4	11.3	6.0	7.3	10.9
95	3.3	8.1	15.6	5.4	10.4	17.9	8.5	12.7	19.5	10.9	14.4	20.4
100	7.1	13.6	23.3	10.6	17.4	26.6	14.4	20.8	29.2	17.9	23.5	30.8

Table 6

The hearing levels in decibels expected of an otologically screened population that has not been exposed to an occupational noise level above 75 dB. The levels are given for both Passchier-Vermeer and Robinson. Rob(75) is Robinson's data assuming the non-occupational exposure of 75 dB. Rob(NN) assumes no significant noise exposure of any kind.

		20 yrs.			*30 yrs.*			*40 yrs.*			*50 yrs.*			*60 yrs.*		
		.9	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*
500	P.V.	−7.0	0	6.5	−7.1	.5	7.7	−6.2	2.0	10.0	−4.3	4.5	13.3	−1.6	8.0	17.6
500	Rob(75)	−7.6	0	7.6	−7.2	.5	8.5	−6.0	1.8	9.6	−4.0	3.9	12.0	−1.2	6.7	14.9
500	Rob(NN)	−7.6	0	7.6	−7.2	.4	8.0	−6.0	1.6	9.2	−4.0	3.6	11.2	−1.2	6.4	14.0
1000	P.V.	−6.9	0	6.6	−7.1	.5	7.9	−6.2	2.0	10.2	−4.3	4.5	13.5	−1.6	8.0	17.8
1000	Rob(75)	−7.6	0	7.6	−7.2	.6	8.7	−5.9	2.0	10.3	−3.6	4.3	12.7	−.6	7.4	15.9
1000	Rob(NN)	−7.6	0	7.6	−7.2	.4	8.0	−5.9	1.7	9.3	−3.7	3.9	11.5	−.7	6.9	14.5
2000	P.V.	−5.5	0	5.5	−6.2	1.0	8.4	−5.0	4.0	13.2	−2.3	8.5	19.7	2.8	15.0	28.6
2000	Rob(75)	−7.6	0	7.6	−6.9	1.1	9.7	−5.0	3.2	12.2	−2.3	6.0	15.4	2.3	10.6	20.0
2000	Rob(NN)	−7.6	0	7.6	−7.0	.6	8.2	−5.4	2.2	9.8	−2.2	5.4	13.0	2.0	9.6	17.2
3000	P.V.	−5.6	0	6.5	−6.5	2.0	10.9	−5.0	6.5	18.1	−1.2	13.0	27.0	5.4	22.5	39.1
3000	Rob(75)	−7.6	0	7.6	−6.5	1.9	10.7	−3.9	4.8	15.0	.3	9.2	20.2	6.0	15.1	26.4
3000	Rob(NN)	−7.6	0	7.6	−6.8	.8	8.4	−4.4	3.2	10.8	−.4	7.2	14.8	5.2	12.8	20.4
4000	P.V.	−8.5	0	10.5	−8.4	3.0	15.9	−4.9	9.5	25.1	.9	18.0	36.0	8.5	28.5	49.1
4000	Rob(75)	−7.6	0	7.6	−6.0	2.6	12.5	−2.1	6.8	17.8	4.1	13.4	25.2	12.6	22.2	34.4
4000	Rob(NN)	−7.6	0	7.6	−6.4	1.2	8.8	−2.8	4.8	12.4	3.2	10.8	18.4	11.6	19.2	26.8
6000	P.V.	−6.4	0	6.1	−5.8	3.5	12.5	−.8	11.5	23.5	6.5	21.5	36.2	15.6	33.5	51.1
6000	Rob(75)	−7.6	0	7.6	−6.0	2.3	11.6	−1.6	7.0	16.9	5.6	14.4	25.0	15.5	24.4	35.4
6000	Rob(NN)	−7.6	0	7.6	−6.5	1.1	8.7	−2.0	5.6	13.2	5.0	12.6	20.4	14.8	22.4	30.0

Table 7

The hearing levels in decibels of non-screened females. Non-noise exposed males should have similar hearing levels. Data are from the 1960-62 Public Health Survey.

	30 yrs.			*40 yrs.*			*50 yrs.*			*60 yrs.*		
Frequency	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*
500 Hz	−1	6	15	0	7	19	1	10	23	4	14	29
1000Hz	−6	1	9	−5	2	13	−4	4	16	−2	7	21
2000 Hz	−6	0	10	−4	2	13	2	6	23	0	8	29
3000 Hz	−4	4	13	−2	6	18	0	9	26	3	16	37
4000 Hz	−5	4	15	−4	6	18	−1	9	26	4	17	43
6000 Hz	3	12	25	5	15	31	8	20	45	15	29	57
⅓(.5,1,2)	−4.3	2.3	11.3	−3.0	3.7	15.0	−.3	6.7	20.7	.7	9.7	26.3
¼(.5,1,2,3)	−4.3	2.8	11.8	−2.8	4.3	15.8	−.3	7.3	22.0	1.3	11.3	29.0
corrected ¼(.5,1,2,3)	−2.3	2.8	9.8	−.8	4.3	13.8	1.7	7.3	20.0	3.3	11.3	27.0

Table 8

The hearing levels in decibels of non-screened U.S. males. Data are from the 1960-62 Public Health Survey.

	30 yrs.			*40 yrs.*			*50 yrs.*			*60 yrs.*		
Frequency	*.9*	*.5*	*.1*	*.9*	*.9*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*
500 Hz	−1	7	15	0	8	19	1	10	21	2	12	26
1000 Hz	−5	0	10	−4	3	15	−3	5	16	−2	6	21
2000 Hz	−4	2	13	−3	4	19	−2	8	28	0	10	43
3000 Hz	−1	9	20	2	13	41	5	19	51	9	30	62
4000 Hz	−1	10	38	4	17	50	8	26	54	12	36	68
6000 Hz	8	18	32	11	24	62	17	31	64	22	46	80
⅓(.5,1,2)	−3.3	3.0	12.7	−2.3	5.0	17.7	−1.3	7.7	21.7	0.0	9.3	30.0
¼(.5,1,2,3)	−3.8	4.5	14.5	−1.3	7.0	23.5	.3	10.5	29.0	2.3	14.5	38.0
corrected ¼(.5,1,2,3)	−1.8	4.5	12.5	.7	7.0	21.5	2.3	10.5	27.0	4.3	14.5	36.0

Table 9

The hearing levels in decibels expected of an otologically screened population that has not been exposed to an occupational noise level above 75 dB. The levels are an average of the levels of Passchier-Vermeer and Robinson.

	30 yrs.			*40 yrs.*			*50 yrs.*			*60 yrs.*		
Frequency	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*
500 Hz	—7.1	.5	8.1	—6.1	1.9	9.8	—4.1	4.2	12.7	—1.4	7.4	16.3
1000 Hz	—7.1	.5	8.3	—6.0	2.0	10.3	—3.9	4.4	13.1	—1.1	7.7	16.9
2000 Hz	—6.5	1.1	9.1	5.0	3.6	12.7	—2.3	7.3	17.6	2.6	12.8	24.3
3000 Hz	—6.5	2.0	10.8	—4.4	5.6	16.6	—.4	11.1	23.6	5.7	18.8	32.7
4000 Hz	—7.2	2.8	14.2	—3.5	8.2	21.5	2.5	15.7	30.6	10.6	25.4	41.8
6000 Hz	—5.9	2.9	12.1	—1.2	9.3	20.2	6.1	18.0	30.6	15.6	29.0	43.3
¼(.5,1,2,3)	—6.8	1.1	9.1	—5.4	3.3	12.4	—2.7	6.8	16.8	1.5	11.7	22.6
corrected ¼(.5,1,2,3)	—4.8	1.1	7.1	—3.4	3.3	10.4	—.7	6.8	14.8	3.5	11.7	20.6

Table 10

The hearing threshold levels for ¼(.5,1,2,3) kHz, ⅓(.5,1,2) kHz, ¼(.5,1,2,4) kHz, and ⅓(1,2,3) kHz for three presbycusis bases. The corrected data refer to a 2 decibel adjustment to the 10th percentile and 90th percentile to account for the expected values for individuals.

Passchier-Vermeer & Robinson

	30 yrs.			*40 yrs.*			*50 yrs.*			*60 yrs.*		
	.9	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*
¼(.5,1,2,3)	−6.8	1.1	9.1	−5.4	3.3	12.4	−2.7	6.8	16.8	1.5	11.7	22.6
⅓(.5,1,2)	−6.9	.7	8.5	−2.5	2.5	10.9	−3.4	5.3	14.5	0.0	9.3	19.2
¼(.5,1,2,4)	−7.0	1.2	9.9	−2.8	3.9	13.6	−1.9	7.9	18.5	2.7	13.3	24.8
⅓(1,2,3)	−6.7	1.2	9.4	−1.8	3.7	13.2	−2.2	7.6	18.1	2.4	13.1	24.6
corrected ¼(.5,1,2,3)	−4.8	1.1	7.1	−3.4	3.3	10.4	−.7	6.8	14.8	3.5	11.7	20.6

Public Health Survey — female

	30 yrs.			*40 yrs.*			*50 yrs.*			*60 yrs.*		
	.9	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*
¼(.5,1,2,3)	−4.3	2.8	11.8	−2.8	4.3	15.8	−.3	7.3	22.0	1.3	11.3	29.0
⅓(.5,1,2)	−4.3	2.3	11.3	−3.0	3.7	15.0	−.3	6.7	20.7	.7	9.7	26.3
¼(.5,1,2,4)	−4.5	2.7	12.2	−3.2	4.2	15.7	−.5	7.2	22.0	1.5	11.5	30.5
⅓(1,2,3)	−6.8	1.7	10.7	−4.7	3.3	14.7	−.8	6.3	21.7	.3	10.3	29.0
corrected ¼(.5,1,2,3)	−2.3	2.8	9.8	−.8	4.3	13.8	1.7	7.3	20.0	3.3	11.3	27.0

Public Health Survey — male

	30 yrs.			*40 yrs.*			*50 yrs.*			*60 yrs.*		
	.9	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*
¼(.5,1,2,3)	−3.8	4.5	14.5	−1.3	7.0	23.5	.3	10.5	29.0	2.3	14.5	38.0
⅓(.5,1,2)	−3.3	3.0	12.7	−2.3	5.0	17.7	−1.3	7.7	21.7	0.0	9.3	30.0
¼(.5,1,2,4)	−2.7	4.7	19.0	−.7	8.0	25.7	1.0	12.2	29.7	3.0	16.0	39.5
⅓(1,2,3)	−3.3	3.7	14.3	−1.6	6.7	25.0	0.0	10.7	31.7	2.3	15.3	42.0
corrected ¼(.5,1,2,3)	−1.8	4.5	12.5	.7	7.0	21.5	2.3	10.5	27.0	4.3	14.5	36.0

Table 11

The hearing threshold levels of 138 noise exposed males age 45-65. The hearing levels of the subjects are rank ordered for each frequency between .5 kHz and 3 kHz. The hearing levels of each individual are also averaged for the frequencies .5,1,2,3, and 4 kHz and the ranking of these values are listed under column "Indiv. ¼(.5,1,2,3)". The data are from the Inter-Industry Noise Study.

Subject		*Frequency*			one fourth *columns*	*Indiv.*			
Rank[x]	*.5*	*1*	*2*	*3*	*.5+1+2+3*	¼[*.5,1,2,3*]	*Diff.*	$\frac{x}{138}$	*Z*
5	0	0	0	5	1.25	6.25	—5.00	.036	1.80
10	0	0	5	10	3.75	8.75	—5.00	.072	1.46
15	5	5	5	15	7.50	8.75	—1.25	.109	1.23
20	5	5	10	15	8.75	10.00	—1.25	.145	1.06
25	5	5	10	15	8.75	12.50	—3.75	.181	.91
30	5	5	10	20	10.00	12.50	—2.50	.217	.78
35	5	5	10	20	10.00	12.50	—2.50	.254	.66
40	10	5	15	20	12.50	13.75	—1.25	.290	.55
45	10	10	15	25	15.00	15.00	0.00	.326	.45
50	10	10	15	30	16.25	16.25	0.00	.362	.35
55	10	10	15	30	18.75	18.75	0.00	.399	.26
60	10	10	15	35	17.50	20.00	—2.50	.435	.16
65	10	10	20	40	20.00	20.00	0.00	.471	.07
73	10	10	20	45	21.25	22.50	—1.25	.529	.07
78	10	10	25	45	22.50	22.50	0.00	.565	.16
83	10	10	25	45	22.50	23.75	—1.25	.601	.26
88	15	10	25	50	25.00	23.75	1.25	.638	.35
93	15	15	25	55	27.50	26.25	1.25	.674	.45
98	15	15	25	55	27.50	27.50	0.00	.710	.55
103	15	20	30	55	30.00	27.50	2.50	.746	.66
108	15	20	30	55	30.00	30.00	0.00	.783	.78
113	20	20	35	60	33.75	31.25	2.50	.819	.91
118	20	25	40	60	36.25	33.75	2.50	.855	1.06
123	25	30	45	65	41.25	37.50	3.75	.891	1.23
128	25	35	45	70	43.75	41.25	2.50	.928	1.46
133	30	40	45	75	47.50	45.00	2.50	.964	1.80

Table 12

The percentage of the population expected to exceed 25 decibels (re. 1964 ISO) for an average of 500, 1000, 2000, and 3000 Hz versus exposure to various average sound levels. The presbycusis data used are the combined data of Passchier-Vermeer and Robinson.

	Age [yrs]	*30*	*40*	*40*	*50*	*50*	*50*	*60*	*60*	*60*	*60*
	Exposure	*10*	*10*	*20*	*10*	*20*	*30*	*10*	*20*	*30*	*40*
Sound Level (dB)	Presbycusis	0	0	0	0	0	0	3	3	3	3
	75	0	0	0	0	0	0	3	3	3	3
	80	0	0	0	1	0	0	5	5	5	5
	85	0	0	0	2	2	2	9	9	9	9
	90	1	2	2	6	7	8	16	18	21	21
	95	3	7	10	14	18	22	28	33	38	43
	100	13	19	28	29	38	47	44	54	64	73

Table 13

The percentage of the population expected to exceed 25 decibels (re. 1964 ISO) for an average of 500, 1000, 2000, and 3000 Hz versus exposure to various average sound levels. The presbycusis data used are the female hearing levels from the 1960-62 Public Health Survey.

	Age [yrs]	*30*	*40*	*40*	*50*	*50*	*50*	*60*	*60*	*60*	*60*
	Exposure	*10*	*10*	*20*	*10*	*20*	*30*	*10*	*20*	*30*	*40*
Sound Level (dB)	Presbycusis	0	0	0	4	4	4	13	13	13	13
	75	0	0	0	4	4	4	13	13	13	13
	80	0	1	1	5	5	5	15	16	16	16
	85	0	2	2	8	8	8	19	20	20	20
	90	2	5	6	14	15	17	25	27	29	29
	95	6	12	15	22	26	30	33	37	41	44
	100	18	25	32	35	42	49	45	52	63	72

Table 14

The percentage of the population expected to exceed 25 decibels (re. 1964 ISO) for an average of 500, 1000, 2000, and 3000 Hz versus exposure to various average sound levels. The presbycusis data used are the male hearing levels from the 1960-62 Public Health Survey.

	Age [yrs]	*30*	*40*	*40*	*50*	*50*	*50*	*60*	*60*	*60*	*60*
	Exposure	*10*	*10*	*20*	*10*	*20*	*30*	*10*	*20*	*30*	*40*
Sound Level (dB)	Presbycusis	0	6	6	13	13	13	27	27	27	27
	75	0	6	6	13	13	13	27	27	27	27
	80	0	7	7	15	15	15	28	29	29	29
	85	1	10	10	19	19	19	31	32	32	33
	90	3	16	17	24	26	28	36	38	39	40
	95	10	24	27	32	36	40	42	46	49	53
	100	23	35	42	43	50	60	52	62	71	73

Table 15

Units of Potential Compensation. The number of decibels above 25 dB (re. 1964 ISO) for a Hearing Threshold Level of an average of the frequencies of 500, 1000, 2000, and 3000 Hz. Data based on 100 people. Presbycusis data used are the combined data of Passchier-Vermeer and Robinson.

	Age [yrs]	*30*	*40*	*40*	*50*	*50*	*50*	*60*	*60*	*60*	*60*
	Exposure	*10*	*10*	*20*	*10*	*20*	*30*	*10*	*20*	*30*	*40*
Sound Level (dB)	Presbycusis	0	0	0	0	0	0	7	7	7	7
	75	0	0	0	0	0	0	7	7	7	7
	80	0	0	0	1	1	1	15	14	14	13
	85	0	0	0	5	5	4	36	34	33	32
	90	1	6	7	24	28	34	89	101	116	115
	95	12	33	47	82	111	139	204	259	311	346
	100	60	125	190	230	327	428	434	578	728	859

Table 16

Units of Potential Compensation. The number of decibels above 25 dB (re. 1964 ISO) for a Hearing Threshold Level of an average of the frequencies of 500, 1000, 2000, and 3000 Hz. Data based on 100 people. The presbycusis data used are the female hearing levels from the 1960-62 Public Health Survey.

	Age [yrs]	*30*	*40*	*40*	*50*	*50*	*50*	*60*	*60*	*60*	*60*
	Exposure	*10*	*10*	*20*	*10*	*20*	*30*	*10*	*20*	*30*	*40*
Sound Level (dB)	Presbycusis	0	0	0	15	15	15	81	81	81	81
	75	0	0	0	15	15	15	81	81	81	81
	80	0	1	1	23	23	22	104	103	103	103
	85	0	6	5	44	43	42	150	149	148	148
	90	5	24	26	92	102	114	234	252	274	276
	95	28	74	98	188	232	271	378	442	500	538
	100	113	202	284	377	489	598	626	769	915	1043

Table 17

Units of Potential Compensation. The number of decibels above 25 dB (re. 1964 ISO) for a Hearing Threshold Level of an average of the frequencies of 500, 1000, 2000, and 3000 Hz. Data based on 100 people. The presbycusis data used are the male hearing levels from the 1960-62 Public Health Survey.

	Age [yrs]	*30*	*40*	*40*	*50*	*50*	*50*	*60*	*60*	*60*	*60*
	Exposure	*10*	*10*	*20*	*10*	*20*	*30*	*10*	*20*	*30*	*40*
Sound Level (dB)	Presbycusis	0	27	27	84	84	84	272	272	272	272
	75	0	27	27	84	84	84	272	272	272	272
	80	0	39	38	106	106	105	309	309	310	310
	85	2	65	64	151	150	150	377	378	380	381
	90	14	120	131	234	251	273	491	519	549	556
	95	54	224	270	374	436	491	672	753	824	873
	100	170	419	531	616	753	890	961	1132	1304	1449

Table 18

The hearing levels in decibels of non-screened males and females. The presbycusis data are from Robinson and Sutton (reference 19).

MALES

	30 yrs.			40 yrs.			50 yrs.			60 yrs.		
Frequency	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*
500 Hz	—6.0	.5	8.7	—5.4	1.7	10.5	—4.4	3.6	13.5	—3.0	6.2	17.6
1000 Hz	—6.0	.6	8.8	—5.3	1.9	10.9	—4.1	4.1	14.3	—2.5	7.1	19.0
2000 Hz	—6.9	1.0	10.9	—5.6	3.4	14.6	—3.6	7.2	20.6	—.8	12.3	28.7
3000 Hz	—7.1	1.7	12.6	—5.0	5.6	18.8	—1.6	11.8	28.5	3.0	20.3	41.9
4000 Hz	—7.3	2.3	14.3	—4.4	7.7	22.9	.3	16.4	36.5	6.7	28.2	55.1
6000 Hz	—8.3	2.6	16.2	—5.0	8.7	25.9	.2	18.4	41.1	7.5	31.8	62.1
¼(.5,1,2,3)	—6.5	1.0	10.3	—5.2	3.2	13.7	—3.2	6.7	19.1	—.8	11.5	26.8
corrected ¼(.5,1,2,3)	—4.5	1.0	8.3	—3.2	3.2	11.7	—1.2	6.7	18.0	1.2	11.5	24.8

FEMALES

	30 yrs.			40 yrs.			50 yrs.			60 yrs.		
Frequency	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*
500 Hz	—6.0	.5	8.7	—5.4	1.7	10.5	—4.4	3.6	13.5	—3.0	6.2	17.6
1000 Hz	—6.0	.6	8.8	—5.3	1.9	10.9	—4.1	4.1	14.3	—2.5	7.1	19.0
2000 Hz	—6.4	.9	9.9	—5.3	2.9	13.1	—3.5	6.1	18.2	—1.1	10.6	25.2
3000 Hz	—6.9	1.1	11.0	—5.5	3.6	15.0	—3.3	7.7	21.4	—.3	13.2	30.1
4000 Hz	—7.3	1.3	12.0	—5.7	4.4	16.9	—3.0	9.2	24.5	.6	—5.9	35.0
6000 Hz	—8.2	1.7	14.2	—6.0	5.8	20.6	—2.5	12.3	30.8	2.3	21.2	44.7
¼(.5,1,2,3)	—6.3	.8	9.6	—5.4	2.5	12.4	—3.8	5.4	16.8	—1.7	9.3	23.0
corrected ¼(.5,1,2,3)	—4.3	.8	7.6	—3.4	2.5	10.4	—1.8	5.4	14.8	.3	9.3	21.0

Table 19

The percentage of the population expected to exceed 25 decibels (re. 1964 ISO) for an average of 500, 1000, 2000, and 3000 Hz versus exposure to various average sound levels. The presbycusis data are the female hearing levels predicted by a compilation of screened data from Robinson and Sutton in 1978.

Sound Level (dB)	*Age [yrs] Exposure*	*30 10*	*40 10*	*40 20*	*50 10*	*50 20*	*50 30*	*60 10*	*60 20*	*60 30*	*60 40*
	Presbycusis	0	0	0	0	0	0	4	4	4	4
	75	0	0	0	0	0	0	4	4	4	4
	80	0	0	0	1	1	1	6	6	6	6
	85	0	0	0	2	2	2	10	10	10	10
	90	1	2	2	6	7	8	16	17	19	20
	95	4	7	10	14	17	21	25	30	34	37
	100	13	18	25	27	35	43	39	46	55	63

Table 20

The percentage of the population expected to exceed 25 decibels (re. 1964 ISO) for an average of 500, 1000, 2000, and 3000 Hz versus exposure to various average sound levels. The presbycusis data is the male hearing levels predicted by a compilation of screened data from Robinson and Sutton in 1978.

Sound Level (dB)	*Age [yrs] Exposure*	*30 10*	*40 10*	*40 20*	*50 10*	*50 20*	*50 30*	*60 10*	*60 20*	*60 30*	*60 40*
	Presbycusis	0	0	0	2	2	2	10	10	10	10
	75	0	0	0	2	2	2	10	10	10	10
	80	0	0	0	3	3	3	12	12	12	12
	85	0	1	1	6	6	5	16	16	17	17
	90	1	3	4	11	12	13	23	25	26	27
	95	5	9	12	19	23	27	32	36	41	44
	100	15	21	28	32	40	47	45	53	62	69

Table 21

Units of Potential Compensation. The number of decibels above 25 dB (re. 1964 ISO) for a Hearing Threshold Level of an average of the frequencies of 500, 1000, 2000, and 3000 Hz. Data based on 100 people. The presbycusis data used are the female hearing levels predicted by a compilation of screened data from Robinson and Sutton in 1978.

	Age [yrs]	*30*	*40*	*40*	*50*	*50*	*50*	*60*	*60*	*60*	*60*
	Exposure	*10*	*10*	*20*	*10*	*20*	*30*	*10*	*20*	*30*	*40*
Sound Level (dB)	Presbycusis	0	0	0	1	1	1	16	16	16	16
	75	0	0	0	1	1	1	16	16	16	16
	80	0	0	0	2	2	2	26	25	25	24
	85	0	1	1	8	7	6	50	48	47	46
	90	2	7	8	29	33	39	104	115	129	128
	95	16	35	50	87	114	141	212	261	306	335
	100	79	127	190	228	318	409	421	546	671	780

Table 22

Units of Potential Compensation. The number of decibels above 25 dB (re. 1964 ISO) for a Hearing Threshold Level of an average of the frequencies of 500, 1000, 2000, and 3000 Hz. Data based on 100 people. The presbycusis data used are the male hearing levels predicted by a compilation of screened data from Robinson and Sutton in 1978.

	Age [yrs]	*30*	*40*	*40*	*50*	*50*	*50*	*60*	*60*	*60*	*60*
	Exposure	*10*	*10*	*20*	*10*	*20*	*30*	*10*	*20*	*30*	*40*
Sound Level (dB)	Presbycusis	0	0	0	6	6	6	47	47	47	47
	75	0	0	0	6	6	6	47	47	47	47
	80	0	0	0	11	11	10	65	65	64	64
	85	0	2	2	26	24	23	104	103	102	101
	90	2	12	14	63	70	80	180	197	217	218
	95	19	48	66	145	183	217	317	379	435	473
	100	88	153	224	317	422	526	561	704	849	973

Table 23

Hearing Threshold levels of a non-screened white population from North Carolina, U.S.A. Presbycusis is from Royster and Thomas (ref. 20).

MALES

	30 yrs.			40 yrs.			50 yrs.			60 yrs.		
Frequency	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*
500 Hz	2.4	7.9	15.0	3.0	9.1	16.0	4.2	10.5	19.8	3.2	10.9	23.8
1000 Hz	—1.0	4.8	12.3	.2	5.8	14.5	1.0	8.9	19.5	—.7	11.6	22.0
2000 Hz	—3.6	3.0	11.5	—1.1	5.8	22.0	1.3	10.3	33.3	1.5	12.5	34.5
3000 Hz	—1.7	5.4	22.5	2.0	11.5	34.5	3.0	20.2	43.8	2.3	26.9	51.0
4000 Hz	.9	11.2	29.0	5.9	16.0	42.0	12.2	26.8	54.0	9.7	37.5	56.4
6000 Hz	3.2	13.7	35.0	8.7	21.7	50.8	14.0	39.4	65.9	16.5	52.2	62.6
¼(.5,1,2,3)	—1.0	5.3	15.3	1.0	8.0	21.8	2.4	12.5	29.1	1.6	15.5	32.8
corrected ¼(.5,1,2,3)	1.0	5.3	13.3	3.0	8.0	19.8	4.4	12.5	27.1	3.6	15.5	30.8

FEMALES

	30 yrs.			40 yrs.			50 yrs.			60 yrs.		
Frequency	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*
500 Hz	2.3	8.2	15.9	3.2	9.1	16.2	3.7	10.7	18.9	4.4	12.9	27.7
1000 Hz	—.4	4.9	11.7	.5	6.2	15.3	2.0	7.7	16.2	3.0	12.7	25.0
2000 Hz	—3.9	3.3	10.3	—2.9	5.7	16.0	—.6	7.3	18.9	.9	10.9	33.4
3000 Hz	—3.0	3.2	11.3	—1.2	5.9	15.3	1.0	10.0	21.5	—.5	14.0	37.3
4000 Hz	—2.0	5.8	14.3	—.2	8.9	20.3	1.8	13.6	28.3	3.5	21.6	44.5
6000 Hz	.8	8.2	19.8	3.4	14.4	23.5	4.7	18.1	30.8	10.0	24.5	50.5
¼(.5,1,2,3)	—1.2	4.9	12.3	—.1	6.7	15.7	1.5	8.9	18.9	1.9	12.6	30.8
corrected ¼(.5,1,2,3)	.8	4.9	10.3	1.9	6.7	13.7	3.5	8.9	16.9	3.9	12.6	28.8

Table 24

Recommended Presbycusis Base for Baughn.

	28[24-29]			*38[36-41]*			*48[42-47]&[48-53]*			*58[54-59]*		
	.9	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*	*.9*	*.5*	*.1*
Actual data from Baughn's table #3.	9	14.9	20.6	10.5	15.6	22.0	11.5	17.6	25.5	13.0	20.0	31.7
Recommended for obtaining Hearing Risk using Passchier-Vermeer and Robinson NIPTS Data.	8	15	21	9	16	23.5	9	17.5	26	10	22	32

Table 25

Percent of the population with a Hearing Threshold Level more than 25 dB at ⅓(.5,1,2) re.1964 ISO. Comparison of ISO Standard (table 7 from Baughn) to the results found by using the combined NIPTS data (table 5) with the recommended presbycusis base for Baughn.

	Age 28 Exposure 10		*Age 38 Exposure 20*		*Age 48 Exposure 30*		*Age 58 Exposure 40*	
	Baughn	*P.V. & Rob*	*Baughn*	*P.V. & Rob*	*Baughn*	*P.V. & Rob*	*Baughn*	*P.V. & Rob*
No-Noise	3	2	6.5	6.3	14	13	33	35
80	3	3	6.5	8	14	15	33	37
85	6	7	12.5	13	22	21	43	42
90	13	11	22	20	32	30	54	50
95	20	21	34	33	45	45	62	63
100	32	36	48	51	58	67	74	81

Table 26

The percentage of the population expected to exceed 25 decibels (re. 1964 ISO) for an average of 500, 1000, and 2000 Hz versus exposure to various average sound levels. The presbycusis data used are the hearing levels from the recommended data base for Baughn of table 24. The NIPTS data is from table 5.

Sound Level (dB)	*Age [yrs]*	*28*	*38*	*38*	*48*	*48*	*48*	*58*	*58*	*58*	*58*
	Exposure	*10*	*10*	*20*	*10*	*20*	*30*	*10*	*20*	*30*	*40*
	Presbycusis	2	6	6	13	13	13	35	35	35	35
	75	2	6	6	13	13	13	35	35	35	35
	80	3	8	8	15	15	15	37	37	37	37
	85	7	13	13	20	20	20	40	40	41	42
	90	11	18	20	25	27	29	43	46	48	50
	95	21	27	32	33	39	45	51	55	51	63
	100	36	42	51	46	57	67	61	69	76	81

Table 27

Units of Potential Compensation. The number of decibels above 25 dB (re. 1964 ISO) for a Hearing Threshold Level of an average of the frequencies of 500, 1000, and 2000 Hz. Data based on 100 people. Presbycusis data used are the recommended data base for Baughn (table 24). The NIPTS data are from table 5.

Sound Level (dB)	*Age [yrs]*	*28*	*38*	*38*	*48*	*48*	*48*	*58*	*58*	*58*	*58*
	Exposure	*10*	*10*	*20*	*10*	*20*	*30*	*10*	*20*	*30*	*40*
	Presbycusis	3	16	16	43	43	43	184	184	184	184
	75	3	16	16	43	43	43	184	184	184	184
	80	5	22	22	54	54	54	206	206	207	210
	85	18	48	47	92	91	91	265	267	270	271
	90	38	79	90	133	148	170	327	355	390	399
	95	98	158	205	230	288	351	464	548	636	694
	100	250	334	470	430	582	747	718	908	1099	1260

APPENDIX

Procedure used to calculate Units of Potential Compensation and Percentage of Population above a certain fence.

1. General

The basic program stores the NIPTS data of table 5 for an average of the audiometric frequencies of .5 KHz, 1 KHz, 2 KHz, and 3 KHz. This data are used to calculate NHTL, by adding it to the desired presbycusis data which are entered by the operator. The resulting NHTL is then printed out (see sample printout). To find the other desired information, the standard deviation is first calculated from NHTL(.1) and NHTL(.5). Then the rest of the calculations are made starting with the .001th percentile. The percentile being used is represented by the value Q in the program. Using the procedure given in section 2, the number (X) of standard deviations above a median are found for this percentile. The value of X is then multiplied by the standard deviation to find the number of decibels above the median and above the fence. This provides an estimate for the range of 0 percentile to .002 percentile. The value of X is then calculated again, using the same procedure for the .003 percentile (which estimates the range of .002 percentile to .004 percentile), and the number of decibels above the fence are added to the previous value. This procedure is continued until the predicted NHTL is below the fence. At this point all calculations stop and the values of X, Q times 100, and the summation of the decibels above the fence (normalized to 100 people by dividing by 5) are printed.

The procedure is then repeated for the next exposure level.

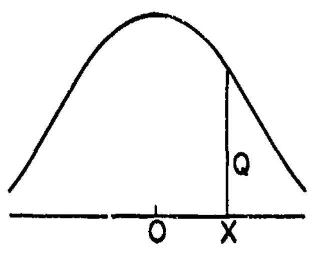
A detailed copy of the program is presented in section 3.

2. Procedure used to determine the value X (the number of standard deviations from the mean or median of a normal curve) given the percentile of the population, Q.

This procedure determines the approximate value of X such that

$$Q = \int_X^{\infty} \frac{e^{-\frac{t^2}{2}}}{\sqrt{2\pi}}\, dt$$

where Q is given and $0 < Q \leq 0.5$.



The following approximation is used:

$$x = t - \frac{C_0 + C_1 t + C_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} + \epsilon(Q)$$

where $|\epsilon(Q)| < 4.5 \times 10^{-4}$

$$t = \sqrt{\ln \frac{1}{Q^2}}$$

$c_0 = 2.515517$ $\quad$ $d_1 = 1.432788$
$c_1 = 0.802853$ $\quad$ $d_2 = 0.189269$
$c_2 = 0.010328$ $\quad$ $d_3 = 0.001308$

Reference: Handbook of Mathematical Functions, Abramowitz and Stegun, National Bureau of Standards, 1968

3. Program used on the Hewlett Packard 9830 calculator for calculating Units of Potential Compensation and percentage of the population above a given number of decibels.

(a) Operation of the Program.

1. Push RUN, EXECUTE
2. Display will read "INPUT AGE, EXPOSURE"
3. Type 30,10 then push EXECUTE
4. Display will read "INPUT SEX(MEN OR WOMEN)"
5. Type WOMEN then push EXECUTE
6. Printer will now output the desired headings
7. Display will read "INPUT .9,.5,.1"
8. Type —2.3,2.8,9.8 then push EXECUTE (Presbycusis Data)
9. Printer will output exposure and calculated data under related headings

(b) Sample Printout

```
SEX  WOMEN
30   YEARS OLD
10   YEARS EXPOSED
FENCE HEIGHT= 25
```

EXPOSURE	PERCENTILE .9	.5	.1	UNITS OF POTENTIAL COMPENSATION	X	PERCENT POPULATION ABOVE FENCE
PRESBYCUSIS	-2.3	2.8	9.8	0.00	3.09	0.1
75DB	-2.3	2.8	9.8	0.00	3.09	0.1
80DB	-2.2	3.4	11.2	0.00	3.09	0.1
85DB	-1.8	4.3	13.6	0.35	2.75	0.3
90DB	-1.0	6.0	17.3	4.78	2.12	1.7
95DB	0.2	9.1	22.4	28.24	1.51	6.5
100DB	3.4	14.0	29.2	113.44	0.92	17.9

****

(c) Listing

```
10 REMARK: 9830 CALCULATOR FOR CALCULATING UNITS OF POTENTIAL COMPENSATION
20 REMARK: AND PERCENTAGE OF THE POPULATION ABOVE GIVEN NUMBER OF DECIBELS.
30 REMARK: L9,L5,L1 ARE THE 90TH,50TH AND 10TH PERCENTILE OF PRESBYCUSIS
40 REMARK: T9,T5,T1 ARE THE PERCENTILES AFTER NIPTS IS ADDED
50 REMARK: F=THE FENCE
60 REMARK:Q=POPULATION ABOVE FENCE
70 REMARK:S3=UNITS OF POTENTIAL COMPENSATION
80 REMARK:X=HOW FAR THE 50TH PERCENTILE IS ABOVE OR BELOW THE FENCE
90 REMARK:S2=THE NUMBER OF DIVISIONS IN EACH PERCENTILE, SUCH THAT THE WIDTH
100 REMARK:   OF THE INTERVAL= 1/S2
110 REM**********************************************************************
120 DIM A$[50],A[24,3]
130 B=0
140 F=25
150 REMARK:C0,C1,C2,D1,D2,D3 ARE CONSTANTS USED IN CALCULATIONS
160 C0=2.515517
170 C1=0.802853
180 C2=0.010328
190 D1=1.432788
200 D2=0.189269
210 D3=0.001308
220 REMARK: READ THE NIPTS DATA
230 FOR I=1 TO 24
240 FOR J=1 TO 4
250 IF J=4 THEN 280
260 READ A[I,J]
270 GOTO 290
280 READ A$
290 NEXT J
300 NEXT I
310 DISP "INPUT AGE,EXPOSURE";
320 INPUT A1,A2
330 DISP "INPUT SEX (MEN OR WOMEN)";
340 INPUT A$
350 PRINT " SEX  ";A$
360 WRITE (15,390)A1;"YEARS OLD"
370 WRITE (15,390)A2;"YEARS EXPOSED"
380 PRINT " FENCE HEIGHT=";F
390 FORMAT F3.0,3X,F4.0
400 PRINT
410 WRITE (15,420)
420 FORMAT 40X,"UNITS OF",14X,"PERCENT"
430 WRITE (15,440)
440 FORMAT 21X,"PERCENTILE",9X,"POTENTIAL",11X,"POPULATION"
450 WRITE (15,460)"ABOVE FENCE"
460 FORMAT "EXPOSURE",10X,".9",5X,".5",5X,".1",4X,"COMPENSATION",5X,"X",4X
470 PRINT
480 FOR B=70 TO 100 STEP 5
490 S3=0
500 S2=5
510 S4=S2
520 IF B=70 THEN 550
530 U5=FNA(1)
540 GOTO 600
550 DISP "INPUT .9,.5,.1";
560 INPUT L9,L5,L1
570 T9=L9
580 T5=L5
590 T1=L1
600 S=(L1-L5)/1.28
610 Q=-0.005/S2
620 Z=(F-L5)
```

```
630 Q=Q+(0.01/S2)
640 IF Q>0.5 THEN 720
650 REMARK:NEXT 11 STEPS FINDS, NHTL FOR A GIVEN PERCENTILE OF THE POPULATION
660 A=LOG(1/(Q*Q))
670 T=SQRA
680 X=T-(C0+C1*T+C2*T*T)/(1+D1*T+D2*T*T+D3*T↑3)
690 IF (S*X-Z)<0 THEN 750
700 S3=(S*X-Z)/S4+S3
710 GOTO 630
720 S=-(L5-L9)/1.28
730 S2=-S2
740 GOTO 630
750 IF S2>0 THEN 770
760 Q=1-Q
770 IF B#70 THEN 820
780 FORMAT "PRESBYCUSIS",4X,F5.1,2X,F5.1,2X,F5.1,2X,F10.2,6X,F5.2,4X,F6.1
790 WRITE (15,780)L9;L5;L1;S3;X;Q*100
800 GOTO 830
810 FORMAT F5.0,"DB",8X,F5.1,2X,F5.1,2X,F5.1,2X,F10.2,6X,F5.2,4X,F6.1
820 WRITE (15,810)B,L9,L5,L1,S3,X,Q*100
830 NEXT B
840 PRINT
850 PRINT "**********************************************************************"
860 PRINT
870 REMARK: DATA IS AN AVERAGE OF 500 HZ, 1000 HZ, 2000 HZ, AND 3000 HZ
880 REMARK: NIPTS DATA FOR 10 YEARS EXPOSURE
890 REMARK.9  .5  .1        %ILES
900 DATA 0,0,0,"            75 DBA"
910 DATA 0.1,0.6,1.4,"      80 DBA"
920 DATA 0.5,1.5,3.8,"      85 DBA"
930 DATA 1.3,3.2,7.5,"      90 DBA"
940 DATA 2.5,6.3,12.6,"     95 DBA"
950 DATA 5.7,11.2,19.4,"   100 DBA"
960 REMARK: NIPTS DATA FOR 20 YEARS EXPOSURE
970 DATA 0,0,0,"            75 DBA"
980 DATA 0.6,0.8,1.4,"      80 DBA"
990 DATA 1.2,1.9,3.8,"      85 DBA"
1000 DATA 2.2,4.2,8.2,"      90 DBA"
1010 DATA 4.2,8.2,14.4,"    95 DBA"
1020 DATA 8.7,14.3,22.3," 100 DBA"
1030 REMARK: NIPTS DATA FOR 30 YEARS EXPOSURE
1040 DATA 0,0,0,"           75 DBA"
1050 DATA 1.4,0.9,1.4,"     80 DBA"
1060 DATA 2.1,2.3,3.8,"     85 DBA"
1070 DATA 3.4,5,9,"         90 DBA"
1080 DATA 6.6,9.9,15.8,"    95 DBA"
1090 DATA 11.8,17.2,24.5,"100 DBA"
1100 REMARK: NIPTS DATA FOR 40 YEARS EXPOSURE
1110 DATA 0,0,0,"           75 DBA"
1120 DATA 2.1,1,1.4,"       80 DBA"
1130 DATA 3,2.5,3.8,"       85 DBA"
1140 DATA 4.8,5.7,9,"       90 DBA"
1150 DATA 8.4,11.3,16.5,"   95 DBA"
1160 DATA 14.6,19.4,26,"   100 DBA"
1170 END
1180 REMARK:SUBPROGRAM BELOW FOR DETERMINING THE NIPTS DATA TO ADD TO L9,L5,L1
1190 DEF FNA(X)
1200 K1=((A2/10)*6)-6+(B-70)/5
1210 L9=A[K1,1]+T9
1220 L5=A[K1,2]+T5
1230 L1=A[K1,3]+T1
1240 RETURN 0
```

REFERENCES

1. Robinson, D.W. and Shipton, M.S. *Tables for Estimation of Noise-Induced Hearing Loss,* Report Ac 61, National Physical Laboratory, England, June 1977.

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   See also

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